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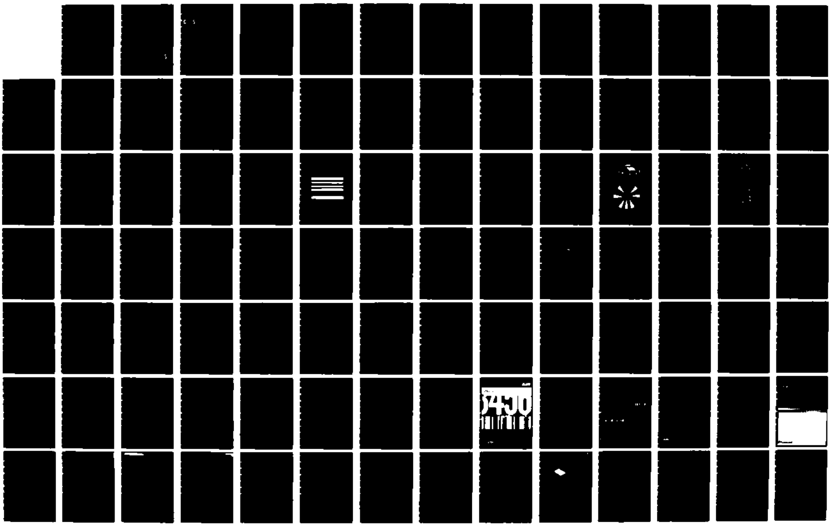

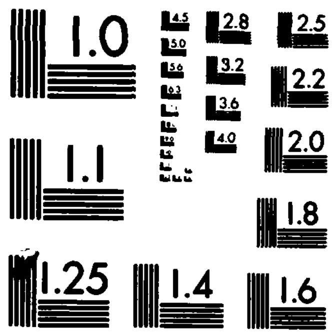

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NVIRONMENTAL MAPPING BY A HERO-1 ROBOT
USING SONAR AND A LASER
BARCODE SCANNER

THESIS

FIT/GE/EE/83D-52 Randall J. Owen, III
1st Lt USAF

DEPARTMENT OF THE AIR FORCE
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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

by
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1st Lt USAF
Graduate Electrical Engineer
December 1983

Preface

The goal of this thesis is to lay the groundwork for a machine capable of performing some of the tasks involved in keeping aircraft in the air. Robots can be used in places where it is dangerous to allow a human. As such, it is not my intention to replace the people doing these jobs with a machine. I would rather make their jobs safer by removing some of the danger.

I would like to thank the members of my committee, Mr. T. Anderson, Dr. T. Jones, Capt D. King, and Capt R. Milne for their help and guidance during this investigation. I would especially like to thank the Air Force Aerospace Medical Research Laboratory for their timely support and funding.

I would like to greatfully acknowledge my advisor, Dr. Matthew Kabrisky, for his ceaseless support, encouragement, and enthusiasm. It has been both a priviledge and a great pleasure to work for him.

Finally, I would like to express my deepest gratitude to my wife, Gigi, and son, R.J., for their patience, understanding, encouragement, and love throughout all the long nights and hectic days. I could not have finished without their support.

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Abstract

The first step in the development of a system to automatically fuel and service aircraft was accomplished. A HERO-1 robot was augmented with ultrasonic sonar and a laser barcode scanner to enable it to rove about and map its environment. Rover software consists of a few simple routines that, when used together, give the rover surprisingly complex behavior. The rover avoids all obstacles while looking for landmarks which enable it to generate a sonar map of its environment stored in memory. Steps for follow on work using a stationary computer as either a peripheral for the rover or as the main controller for the system were taken.

In the course of this work, numerous modifications were made to the HERO-1 . The memory was expanded from 4K bytes to 36K bytes. Two sonar systems (one for object detection the other for mapping) using Polaroid transducers and associated control circuitry were added. An RS-232 port to enable more efficient communication between the rover and any peripheral was included. Finally, an Instaread IR-1 Laser Barcode Scanner was installed, enabling the rover to locate designated objects at a range of up to five feet without the cost and time inefficiency of a full vision system.

The results include a sonar map of a test environment made by the rover.

CHAPTER I

The pilot eases the nose of his plane onto the runway, reverses the thrust, and applies the brakes hard as he rolls to a stop on the damage shortened strip. The airfield is a cratered chaos with rubble strewn everwhere except the hastily patched runway and taxiways.

Carefully he taxis his fighter to the location specified by the tower controller. A voice in his helmet asks "What can we do for you today sir?"

The pilot answers, "Fill the fuel tanks, top off the LOX and check the backup nav radar."

"Right away Sir," the voice replies.

As the pilot checks his cabin seal to make sure that he is not contaminated by the air outside, he notices the service vehicle pulling around the front of his aircraft. While he is accustomed to its familar sight, it is anything but ordinary. The vehicle is an autonomous, mobile robot, capable of performing the requested tasks on its own as well as communicate with the pilot in natural speech.

The service robot moves smoothly around the aircraft as it completes its task. "All finished sir," the robot broadcasts as it backs up to perform the preflight safety checks. When finished the robot slowly trundles back to its shelter. The pilot asks the tower for takeoff clearance and direction. He then taxis the plane to the end of the

runway, opens the engines up full, and does a maximum performance takeoff from the shortened strip. He ascends without ever interacing directly with another human being the entire time the plane was on the ground.

The preceeding is science fiction today, but is a real possibility in the not too distant future. This thesis is a first step towards the day where a autonomous device can perform a complex task without the need to expose a human to a potentially hazardous environment.

Background

Robots can be divided into two distinct categories. The industrial robots, usually consisting of an arm and a controller, can be programmed to perform complex tasks, such as welding and painting, with a high degree of precision. They are much more numerous than the mobile, autonomous, multi-purpose robot.

Before the development of the microprocessor, the mobile robot was impractical to build due to the large dimensions required to house the power supply and control circuitry, and the cost of a mainframe computer. Nevertheless, some were constructed. They were capable of performing limited tasks, usually slowly, and were in constant communication with a mainframe computer for control and decision making. The early robots were more a peripheral device for a stationary computer than an

autonomous machine in their own right.

The advent of the microprocessor provided a means of performing the calculations required for robot onboard control. Microprocessors are not only small in size, but consume much less power than their predecessors. This means the robot can have smaller batteries and motors along with greater capabilities than a multi-chip processor based system . The microprocessor's low cost also introduced the possibility of having a processor for each robot activity and a supervisory processor to coordinate the separate activities. An initial attempt to construct a robot from scratch was made at the Air Force Institute of Technology (AFIT) (1). However, The varied tasks involved proved too great to accomplish in a single graduate thesis.

In December of 1982, Heathkit began production of a low cost robot called HERO-1 (short for Heath Educational RObot-1). The machine proved to be an excellent point of departure for this investigation. HERO-1's initial capabilities included environmental sensors, a five degree of freedom arm, a votrax speech synthesiser, a steerable drive motor, and a 6808 based microcomputer. (See Appendix H for more details.) AFIT purchased a HERO-1 which, after some modifications, has served as the hardware foundation of this research.

Statement of Problem

The emphasis of this thesis is on the development of an autonomous device capable of solving the "rover problem". The solution of the rover problem is categorized by the ability of the device to gather information needed to characterize and move through its environment. It also requires the ability to either prevent entry into or permit extracation from entrapment by any obstacles present in the environment. This requires the integration of a large body of engineering expertise (eg. motors, analog and digital circuit design, environmental detection and sensing, etc.) into a single machine. Fortunately, by using the HERO-1, a large amount of the groundwork has already been accomplished.

Scope

The task to be completed in this thesis is the construction of an autonomous robot rover capable of generating a memory map of its environment, which can be used in future investigations. The goals which must be accomplished to achieve this are:

1. Adaptation of the HERO-1 robot to enable it to gather adequate environmental information.

2. Generation of low level housekeeping software to take care of routine rover functioning and the generation of an overseer program to orchestrate the lower level functions into a complete

system.

3. Demonstration of the entire system by allowing it to characterize a test area.

4. Finding parameters that can be measured and analyzed to evaluate the success of the system.

5. Maintain system flexibility and expandability for follow on research.

Approach:

This thesis is presented in chapters covering logical divisions of the task.

Chapter II discusses the task definition for the problem along with some background information and insight into the final task.

Once the tasks were defined, the information required about the environment that the robot had to assimilate was identified. Chapter III contains the description of the environmental features and the details about the sensors needed to gather it.

Chapter IV is a description of the basic HERO-1 robot and the adaptations made to it in the course of this research.

Chapter V contains the discussion about the required software. The actual software listings appear in appendix A.

The description of the system integration and testing is contained in Chapter VI.

Data collection and analysis is discussed in chapter VII.

Finally, recommendations for follow on research using the HERO-1 system are made in chapter VIII.

CHAPTER II

Task Definition:

The primary task of the robot is to gather the data required to analyze its environment in enough detail to provide for navigation, location, and relocation of items of interest.

This thesis is aimed at developing initial hardware and low level software needed to accomplish this task. Advanced studies using Artificial Intelligence programming techniques will be deferred until a later investigation.

Pattern Recognition Tasks and Sensors Required by the Autonomous Robot Rover:

The design of a device capable of solving the robot rover problem (hereafter refered to as the rover) requires only a limited set of behaviors. These behaviors can be combined to yield a complex response to the rover's environment using a relatively small amount of code. The complexity of the rover lies in the selection of features for the pattern recognition programs and the sensors used to look for these features.

Before any determination of what features are to be measured the operational goals and environment of the rover must be examined. For instance, if the rover will be used in a hostile environment, sensors capable of detecting any potential insult to the rover must be included. If the

environment contains people, animals, or any other easily damaged article, sensors should be included to detect them. At the same time, any sensors capable of doing any damage (for example lasers mounted at eye level) should be avoided. Finally the characteristics of the goal task should be examined carefully to ensure sensors capable of finding the desired object, or location, and separating it from potential environmental noise are included.

When evaluating potential pattern recognition procedures and sensors, it is important to avoid an anthropocentric viewpoint. The human perception system is very flexible, but at the same time it is limited as to the type of information it can process. To restrict the rover's sensors to the region of the environment perceived by the human senses might seriously complicate feature extraction and yield an inefficient design. By using the entire audio and electromagnetic spectra as well as lasers, radiated Electro Magnetic (EM) fields, etc., the rover can have a richer view of its environment than that imposed by the human senses. This can greatly simplify the identification calculations and yield a faster more efficient system.

Rover Tasks:

The tasks performed by the rover can be separated into several areas; environmental sensing and detection, internal and external control of the rover, and rover control of the environment. The detection task can be subdivided into

obstacle, location, and goal detection.

Environmental Sensing and Detection:

Environmental sensing and detection is an important problem that must be paid close attention. If the rover is unable to gather adequate data about the environment it will never be able to perform its task with any kind of speed or efficiency.

Obstacle Detection:

When moving about freely in the environment the rover must be capable of detecting objects in its path, preferably without direct contact. One obvious way to accomplish this is to use some type of vision system. To get depth information at least two views of the environment are required for parallax imaging. This means either two (or more) cameras or one movable camera are required.

Vision systems are very rich in information and therefore require large computational overhead and large memory space. This tends to make systems using them slow and costly.

Other methods to detect obstacles are sonar, radar, and pulsed light. A sonar system is easy to design using commercially available transducers and driver circuitry (see Appendix D). A large number of the transducers can be spaced around the rover and examined individually to not only detect an obstacle, but determine its bearing and

range. Incorporating a large number of transducers into a phased array could acheive resolution approaching that of an optical vision system. A radar system could also be implemented in the same manner using radiating/receiving antennas in place of the sonar transducers.

A pulsed source of light could also serve as a source of energy whose reflection would indicate an approaching object. By using a phase-locked-loop a reflected Infra Red (IR) pulse can be detected in the presence of the large amount of extraneous light in most environments. Several IR Light Emiting Diode (LED) Phased-locked-loop detector systems, each operating at a different pulse frequency, can be used to monitor the entire rover perimeter continuously without adjacent units interfering with each other. This method provides no bearing and range information other than that an object either is or is not close enough to trigger the detector.

Instead of using reflected energy, a standing wave pattern can be set up and an object detected by the irregularities it induces. An externally located continuous Radio Frequency (RF) field can be loosely coupled to an antenna on the rover. Whenever the rover approaches an obstacle, the obstacle's presence will change the dielectric constant of the space in the vicinity of the antenna. This changes the antenna's resonant frequency which in turn changes the output signal amplitude. The beam pattern of a non-isotrophic antenna can be used to pay extra attention to

certain angular orientations (such as straight ahead). Ranging information may be obtained indirectly from the way the return varies as the obstacle is approached.

This system has been implemented sucessfully on an autonomous mail delivery cart manufactured by Lear Siegler Inc. (2).

Goal Detection:

In addition to general object detection, the rover must be able to detect, recognise, and locate specific objects of interest. These objects can either be landmarks or items related to the performance of the rovers primary task (hereafter called the goal). A means of finding these goal objects is required. A system analysis similar to that discussed previously for the obstacle detecton system is in order.

To recognise specific objects either the rover must have a pattern recognition vision system or the objects must be marked in a manner which makes them stand out when viewed with a special sensor.

When considering what type of sensors to choose, once again the first system that comes to mind is a vision system. Vision is particularly attractive if the rover is deisgned as a multiple mission device. It can be made capable of detecting many goal objects simply by changing the recognition software. The vision processing and memory demands are still costly and must be considered when making

design tradeoff decisions.

A simpler way to detect a goal object is to mark it with some type of label. A flashing light, with a predefined period or pattern, could be used as a beacon for the rover to home in on.

Alternatively, if each object is marked with a code, such as a bar code, the rover can be equipped with a suitable scanner. A system of this type can be viewed as a hybrid visual system capable of selectively filtering out all visual information but the desired code. This method greatly reduces the processing overhead and memory requirement while maintaining flexibility, provided the user is willing to affix a lable to the objects of interset.

Another, more conventional, method is to place a transponder on the objects which the robot could activate using either a sound or EM transmission. This is the simplest of the methods discussed, but it requires a compliant object and a marker which is itself an active device, subject to the failure of its parts or power supply.

Location Detection:

The rover requires some knowledge about its location in space, either in absolute terms or with respect to its goal. There are many types of absolute reference systems in use today. Each varies in scale and the means used to provide a reference. Most methods incorporate some type of triangulation or phase/frequency shift of a set of reference

points or beacons.

The choice of references is a matter of scale. A rover with a range of several kilometers, or more, could use a constellation of the Global Positioning System or a Loran C (3) type navigation system. If the scale is smaller, IR point sources can be set up at three (or more) points visable from anywhere within the operating perimeter and the location triagulated (4). Instead of triangulating from known reference points the environment can be labled with an x-y type coordinate grid allowing the rover to directly read its location as it moves along.

A different approach is to determine location using the rover's relative position with respect to the goal object. This is rather limited in that it does not help in the initial accquisition of the object, but aids in making decisions after locating it. This option is useful for tasks requiring multiple approaches to the located object with intermediate sub-tasks performed at another location. For example; servicing of a vehicle requiring cargo to be unloaded, carried a distance, and set down repeatedly.

Another interesting method detects not where the rover is, but if it has been there before and possibly how much time has elapsed since its last passage. The rover could be equipped with a "foot", capable of depositing an evaporative chemical trail, which it would drag on the ground. Used in conjunction with a chemical sniffer or simple electrode pair, the trail could be located when it is crossed. This

would provide a method of determining if the location has been previously examined or alternatively be used as a trail to retrace the rover's path.

Control of the Rover:

The day of the truly intelligent machine is approaching, but as yet no machine exists that is both small enough to be portable and large enough to do all the computation required for the total control of the rover. This means that, in any present rover system, some external means of control is required. Control can come from either a main-frame computer or a human being.

Computer control will probably be maintained by means of an RF link. A two way link would be preferable. However, a one way system could be servicable, particularly if the loop is closed using additional sensors located throughout the environment in such a way as to monitor the location and operation of the rover. The computer could be used as the system controller or as a high power number crunching peripheral for the rover.

If a human is used to monitor or control the rover, the information could again be sent via an RF link. A more general and convenient means of communication would be natural speech. The rover would incorporate a speech recognizer for input and a speech synthesizer for output. This would enable the rover to not only perform its rover tasks but would allow real-time interaction between a human and

the machine. This would prove particularly useful in environments where a human is needed for judgement but a machine is used to perform the labor.

Rover Control of Its Environment:

The rover must be able to control its environment physically and verbally. If the rover is working with a human, a voice synthesis/recognition system is a useful addition to provide easy communication without the need for control panels or keypads. Speech is also faster since most people can talk and listen while performing another task where as typing keys and reading a display usually require full attention.

The rover will ususally include some type of manipulator arm and end effector. The task dictates the specific equipment design, but in general it involves some type of physical manipulation such as lifting, moving, painting, welding, etc.. Some tasks, such as reconaissance or monitoring do not require the rover to be equipped with a manipulator arm.

Rover Control Programing:

Rover problem solving can be viewed as a subset of Artificial Intelligence (AI). As such, it can take advantage of expert systems and advanced programing languages such as LISP.

The decisions made by the rover program are not simply

logical yes or no, but are value judgements based on the combined contribution of many factors. Decisions of this type are particularly suitable for modeling using fuzzy variable techniques. Potential fuzzy variables include mission priority, percent of task completed, amount of time spent on task, amount of charge remaining in the batteries, intensity of any hazardous substance or radiation level, etc..

CHAPTER III

Environmental Features:

The rover's environment (at least for this investigation) is an indoor lab or classroom. Each room has a tile floor, scattered furniture, and moving people. All doors are kept shut while the rover is operating. No room has steps or any other kind of drop-off obstacle. There are numerous tables that are just slightly lower than the rover's required clearance.

From the above description, it is apparent that the rover needs some type of obstacle detection system as well as a navigation and object recognition system. Since people are present in the environment, care must be taken to avoid sensors that can injure. The obstacle detection must operate in real time to detect someone walking in front of the moving rover.

Obstacle Detection:

Several different systems for obstacle detection were investigated. Among them were the pulsed IR phase-locked-loop, the loosely coupled RF radiator, and the sonar systems discussed in the previous chapter.

Pulsed IR Phase-Locked-Loop Obstacle Detection:

In his book on Android Design (5) and a later article in Robotics Today (6) Weinstein discusses "Optical Wiskers" for noncontact object detection in the area adjacent to the robot. The system uses a phased-locked-loop to detect the returned pulses even if they are buried in the noise of the room lights. Several modules are spread around the perimeter of the robot at several different heights. Each module operates at a different frequency permitting all of them to be operated simultaneously. The modules are relatively inexpensive to build. However, they were discarded in this investigation due to the time required to obtain parts and build the numerous modules needed.

Loosely Coupled RF Radiator:

The system described by Houskamp(2) for obstacle detection measures the change in the dielectric constant of the space surrounding an antenna. If a transmitter is tuned to the resonant frequency of the detector antenna then detuned to a slightly higher frequency the signal voltage from the antenna will increase whenever the rover approaches an object.

This system was investigated using a variety of coils and antenna orientation and some promising results observed.

Sonar:

Polaroid has a commercially available sonar experimental kit containing two sonar transducers, a transducer driver board, and a controller board (see Appendix D). Two of these kits were available for experimentation. The system gives the distance to the nearest object in BCD with a resolution of 0.1 feet and range of 0.9 to 35 feet. The transducers have a viewing angle of roughly 20 degrees between 3dB points.

The HERO-1 comes equipped with a sonar system which uses two transducers, one as a transmitter and the other as a receiver. Five inch diameter plastic tubes are used to mount the transducers. The pipes reduce the viewing angle of the system to only a few degrees. The transducers are controlled by the robot language software on the robot making them easier to use than an external system. However, the angular constraint imposed by the mounting pipes limits the systems utility as an obstacle detection system.

A sonar based system using the present sonars for high resolution measurements, augmented by the Polaroid system, proved quite capable of detecting obstacles in front of the moving rover.

Final System Configuration:

After conducting the above comparison the sonar system was decided upon as the obstacle detection system to be used. This decision was based primarily on the ease of the

Polaroid system's adaptation and integration into the existing system while requiring a minimum of additional circuitry.

Object detection:

As discussed in the previous chapter it is impractical to attempt to use full vision for detecting objects of interest to the rover. This means that the system of choice must use designated objects. After reviewing the literature, a barcode reader was selected to detect the objects of interest. This was easier to implement than any other method because off the shelf hardware was available from the Control Laser Corporation. The Instaread-1 barcode scanner not only reads barcodes at a reasonsable distance (up to 5'), but contains a programmable controller that frees the rover processor from reading the codes. Information from the scanner is made available on a standard RS-232C interface.

Navigation:

The initial means of navigation considered used three IR beacon lights spaced in three corners of the test environment as described by Julliere (3). Two of the beacons are identical, the third is distinguished by a different flash frequency. By detecting at least two of the beacons, the rover could triangulate its location.

The beacon approach requires a large amount of hardware

and computational software development. In contrast the laser scanner was a completely developed device requiring only integration into the system. For this reason the decision to use the barcode scanner as the navigation system was made.

The scanner was mounted so that by using a pivotable mirror, it can read both straight down and forward. This enables the scanner to see codes affixed to the ground as well as looking straight ahead when the mirror is pivoted out of the beam.

The navigation system uses a two-dimensional grid of two character barcodes as reference objects. Since bar codes are designed to be read in either of two orientations (top up or bottom up) a means of determining the rover's angular orientated is required. This was provided by using the rover's light sensor (mounted halfway up on the left side of the head) and a bright light positioned at sensor level on one side of the test environment (see figure VII-1). When a code is read the light sensor is also examined and the light level compared with a calibration value to determine the rover's rotational orientation.

Barcodes:

The Instaread-1 barcode reader is capable of reading several different code formats (see Appendix E). The code selected is code 3 of 9 (see Appendix C). Code 3 of 9 symbols consist of 5 dark lines separated by 4 white spaces,

yielding a total of nine positions. In each symbol, three characters are wide with the other six being narrow, thus the name 3 of 9. By varing which positions hold the wide characters the symbols are differentiated. This type of system is very resistant to substitution errors due to damaged codes. Besides the encoded information, code 3 of 9 includes special start and stop characters which must also be read correctly. See figure III-1 for a sample bar code.

Since a large number of different barcodes are used, a means of generating the codes locally is required. A code generation program was written in BASIC on a Commodore 64 computer and the codes printed on a Star Gemini-10X printer. The program was modified to run on the Cromemco Z2-D computer and Anadex printer located in the Signal Processing Laboratory at AFIT (see Appendix B for listing).

Navigation grid codes consist of two digits running consecutively from 00 to FF, yielding 256 different codes. Since there are 40 different code 3 of 9 symbols available, a two-digit system could be extended to a 40 x 40 grid with 1600 different locations specified by the two symbol code.

Object identification codes can be any code not used in the navigation system. Code length can be changed to one or three characters or the remaining 3 of 9 characters (excluding 0-9,A-F) can be incorporated.

A F

Figure III-1: Sample Barcode

CHAPTER IV

Alterations and Adaptation of the HERO-1 Robot

The HERO-1 robot comes equipped with a variety of senses and capablities. Many of these were quite adequate for the accomplishment of the thesis goals. However, as explained in this chapter, some modification of existing hardware and addition of other systems was required.

The first modification of the HERO-1 was the expansion of the onboard Random Access Memory (RAM). The standard HERO-1 has only 4K (1K = 1024) bytes of RAM. This was expanded to 36K bytes. The RAM expansion board is mounted on the inside of the chasis access door. The circuit consists of 4-EDH8808, 8k RAM chips (see Appendix F for a data sheet), a 74LS245 bi-directional octal buffer on the data bus, a 74LS22 dual 4-input logical and gate for bus direction selection, and a 7805 positive 5-volt regulator. The data bus, address bus, and other required signals are obtained from connectors P406 & P408 and the extra Read Only Memorry (ROM) socket (number U417) on the HERO-1's micro-processor board. The signals are then routed to a 50 pin ribbon cable connector on the RAM expansion board. The added 8K blocks of memory are located at 4000-5FFF, 6000-7FFF, 8000-9FFF, and A000-BFFF in the memory map. This arrangement was chosen, even though it results in empty addresses from 1000-1FFF, because decoding circuitry for

these locations is already present on the microprocessor board.

The addition of the laser barcode scanner required the modification of the rotating head. The Control Laser Insta-Read I scanner is approximately 21" long by 5.5" square and weighs approximately 14 lbs. (see Appendix E). In order to prevent the generation of a large moment of inertia when the head is rotated, the scanner must be mounted with its center of gravity along the head motor's axis of rotation. This also prevents undue strain on the head bearings.

One mounting possibliity would have been to mount the scanner directly on top of the existing head, this was unacceptable because the keyboard and display would have been covered. In the final mounting design the keyboard, display, and sonar tubes are elevated 11" using 3/8" diameter rod spacers and an aluminium plate. This made room for the scanner and other equipment, formerly in the head, to be mounted in the space created in the middle of the robot.

In order for the robot and the scanner to communicate, an RS-232C standard interface was required. The interface was constructed from a General Instruments AY-5-1013 Universal Asynchronous Receiver and Transmitter (or UART), Motorola MC-14411 baud rate generator, MC-1488 and MC-1489 signal level matching/buffering chips, and buffering and power conditioning circuitry following a design by Ciarcia

(7). The interface was mounted on the same board as the memory expansion to provide easy access to the data bus. In addition an RS-232C female connector and switch to select either the Data Terminal Equipment (DTE) or Data Communication Equipment (DTC) connector configuration (switch pins 2 and 3) were mounted on the external side of the access door. The software controlling the interface is presented in Appendix A.

As mentioned previously, the sonar system of the standard HERO-1 was too limited. Augmentation of the sonar was carried out using Polaroid sonar transducers and driver circuitry (see Appendix D).

The two sonar tasks of obstacle detection and environmental mapping were divided between two separate systems.

In a discussion with Polaroid's technical consultation service it was learned that the driver boards are capable of driving a maximum of two transducers. Since many transducers were required and only two driver boards available, one driver board was dedicated to each system and multiplexing circuit designed to switch the signals to and from the transducers.

The obstacle avoidance task was handled by four pair of transducers concentrated on the front panel of the rover (see Figure IV-1). A four channel multiplexor circuit was constructed using dual inline package relays. The relay contacts are rated at 12 volts which is nowhere near the

300+ volt pulse applied to the sonar transducers they are required to switch. Since the contacts are rated at the maximum voltage at which they can make or break a connection without burning up, the rating could be exceeded by assuring that the switching takes place when no 300 volt pulse is present. Fortunately, the 5 volt System Reset (SR) signal on the Polaroid Experimental Display Board (EDB) is pulsed when the sonar driver pulse is absent, allowing the relay switching to take place without 300 volts across the contacts (see Appendix G). The sonar information was interfaced to HERO-1's processor by using the experimental data port provided. The multiplexed distance information is available directly via the data bus connections. A hardwired interrupt signals the processor whenever any of the transducers senses an object within the deceleration envelope (the area in which the robot can come to a stop) surrounding the robot. The use of an interrupt frees the processor from having to continuously examine the distance.

The mapping sonar uses eight sonar transducers placed around the perimeter of the robot's head (see Figure 3). The transducers can be individually examined by the system's microprocessor. Three bits of the data-out bus on the experimental board are used by another dip relay network to select the correct transducer (see Appendix G). Using this system, the rover has a panoramic view of the environment without the time consuming task of turning its head.

Additional relay switching circuitry was required to

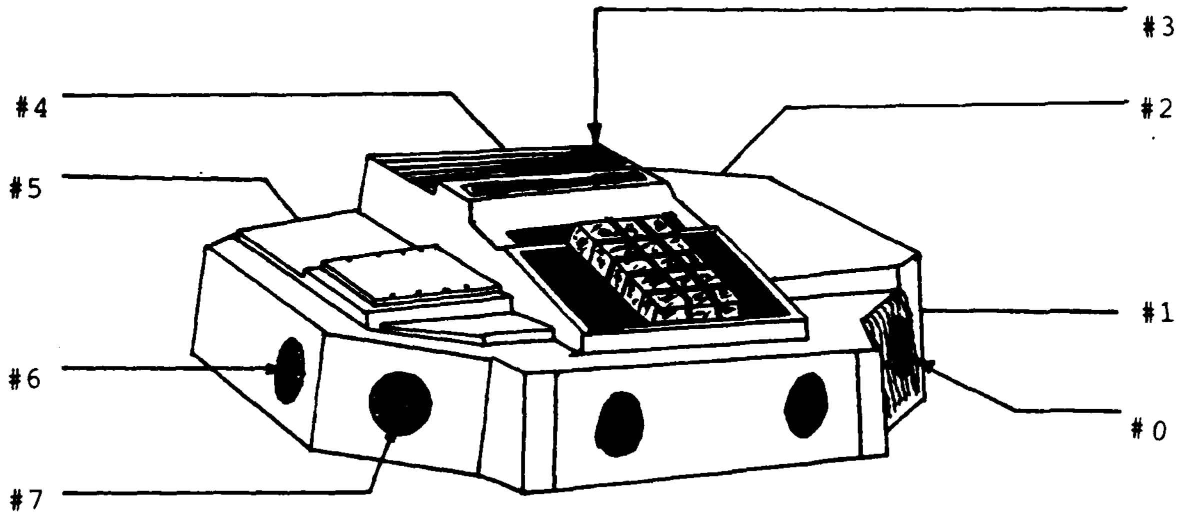

Figure IV-2: Mapping Sonar Transducer Locations

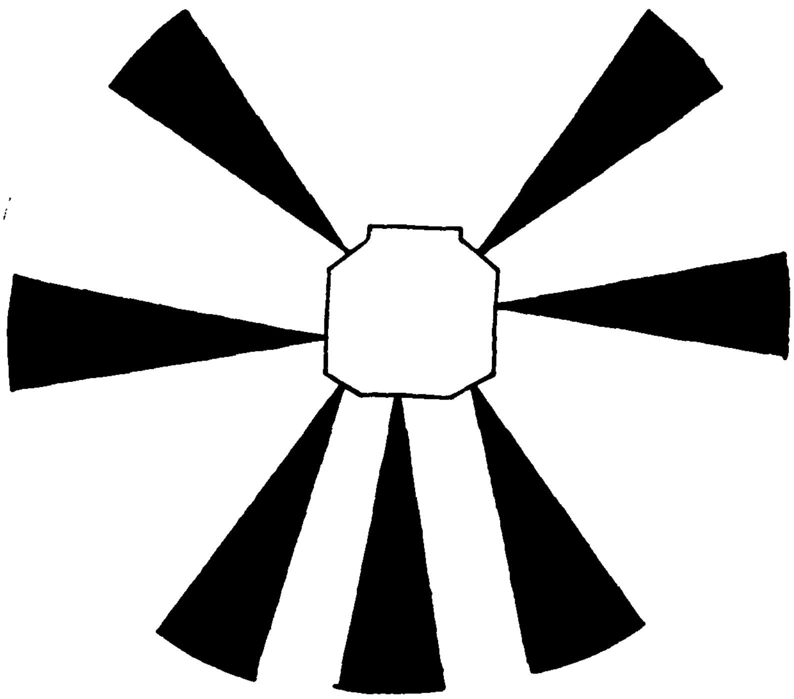

Figure IV-3:Mapping Sonar Viewing Angles

prevent simultaneous operation of the two sonar systems and allow the microprocessor to enable the desired system.

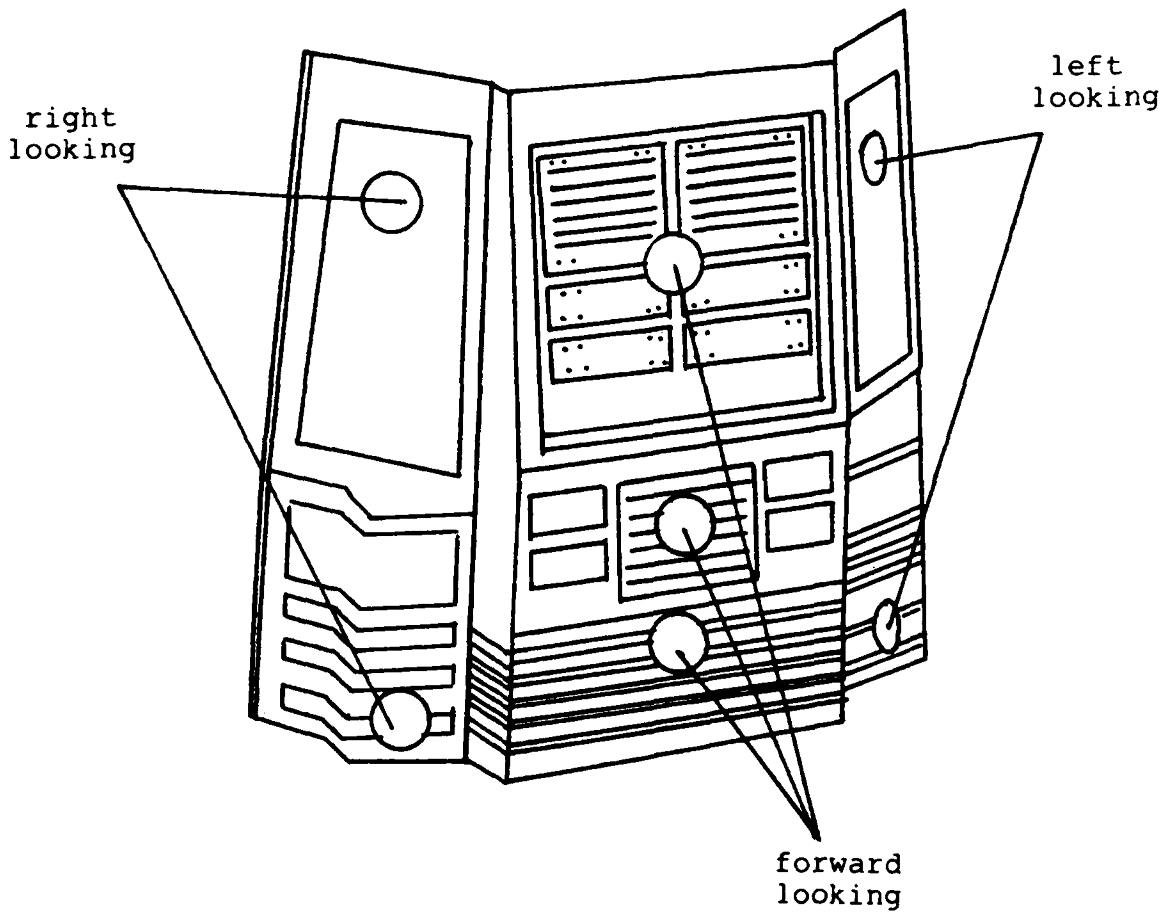

Figure IV-1: Obstacle Sonar Transducer Locations

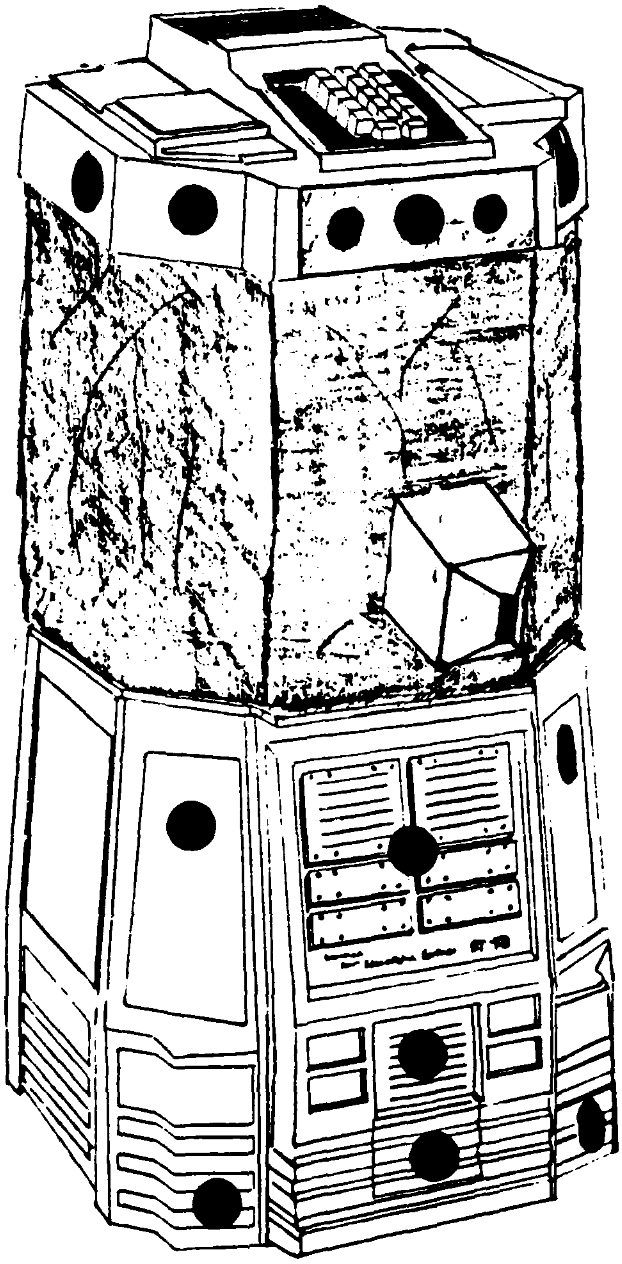

Figure IV-4: Final Robot Configuration

CHAPTER V

Rover Software

The initial task of mapping the environment is divided into six subtasks and implemented using 11 machine code modules. The actual code is in Appendix A.

The first subtask was the initialization of the interrupt vectors for the "obstacle detection" and "barcode read" interrupts. These must be stored at 002A-002C and 002D-002F respectively.

The second subtask is the initialization of the environment map memory region to contain all zeros.

The third subtask is the examination of the interrupt words and taking the action prescribed by their status.

The fourth subtask is the building of the map using the detected barcode as the basis for the address calculation and the storing of the eight panoramic sonars, the light intensity seen by the light sensor, the sound intensity and finally incrementing the counter word. The format used to store the map in memory is shown in table V-1.

The fifth subtask concerns the control of the RS-232C port and hand shaking with the laser scanner.

The final subtask directs the rover in the avoidance of detected obstacles.

```
Bxx0 - Range from Tranducer #0
Bxx1 - Range from Tranducer #1
Bxx2 - Range from Tranducer #2
Bxx3 - Range from Tranducer #3
Bxx4 - Range from Tranducer #4
Bxx5 - Range from Tranducer #5
Bxx6 - Range from Tranducer #6
Bxx7 - Range from Tranducer #7
Bxx8 - Light Sensor Level
Bxx9 - Sound Sensor Level
BxxA - Counter (incremented each
                 time code seen)
BxxB - Unused
BxxC - Unused
BxxD - Unused
BxxE - Unused
BxxF - Unused
```

xx - value of barcode read is used as the middle two bits of the data address

All data is stored in Hexidecimal form.

Table V-1: Memory Storage Format

CHAPTER VI

System Integration and Testing:

Integration:

System integration was accomplished by physically mounting the laser, the additional sonar transducers, and the memory expansion/RS-232C board on the HERO-1 and connecting the laser to the RS-232C connector.

System Testing:

Testing of each subsystem was completed as follows:

Memory:

The individual blocks were written into and then verified as being correct. The robot was put into the "sleep" mode, then reawakened and the memory reexamined to verify that the board was not powered down during sleep. Finally the robot was put to sleep and left overnight. Upon awakening the next day the memory was again reexamined to verify long term stability. The memory passed these tests and functioned as expected throughout the thesis.

RS-232C Port:

The easiest way to test the port circuitry was to connect it to the robot's processor and a Heath-19 terminal. The I/O software was run and bidirectional communication

verified.

Laser Scanner:

Prior to mounting, the laser was connected to a Heath-19 terminal and its ability to communicate, as well as read barcodes, was verified. This was performed again after mounting onboard the robot. Finally, the robot was loaded with the communication software and connected to the scanner. It also functioned as desired.

Obstacle Detection Switching Module and Sonar System:

After assembly, the Switching circuit was tested using a clock input from an external source. To make the relay status more apparent, 4 LEDs were added to indicate which channel was selected. Once verified externally, the sonar driver and transducers were added and the whole system verified. It worked satisfactorily.

Panoramic Selection Module and Sonar System:

The selection module was built and tested using external selection inputs and clocking. Upon verification that the module functioned correctly it was installed in the robot and exercised using three experimental board data out lines to select the desired state. Finally the transducers and driver circuitry were added and connections to the decoder module made. The whole system was tested and found to be functioning properly.

CHAPTER VII

Data Collection and Analysis:

In order to evaluate the systems performance a test area was constucted using an irregularly shaped grid of 51 barcodes spaced on 1.5 foot centers (see Figure VII-1). The system software was designed to accommodate a 16 x 16 grid but space limitations forced using the smaller area. The area was surrounded by desks and other furniture presenting a solid perimeter at sonar height. This served two purposes. First it provided a definite boundary for the mapping sonars, second it served to keep the rover confined to the test area. A 3'x2'x2' cardboard box was placed in the center of the main section of the grid to provide an object in the interior of the test area.

Data Collection:

The rover was programmed, placed in the test area, and activated. It apparently performed the mapping and obstacle tasks without any problems. However, when the data were examined the mapping information for the codes read were either missing or in incorrect locations. The cause of the problem was found to be a damaged line of code. The code was corrected and the run repeated. This time everything went as planned.

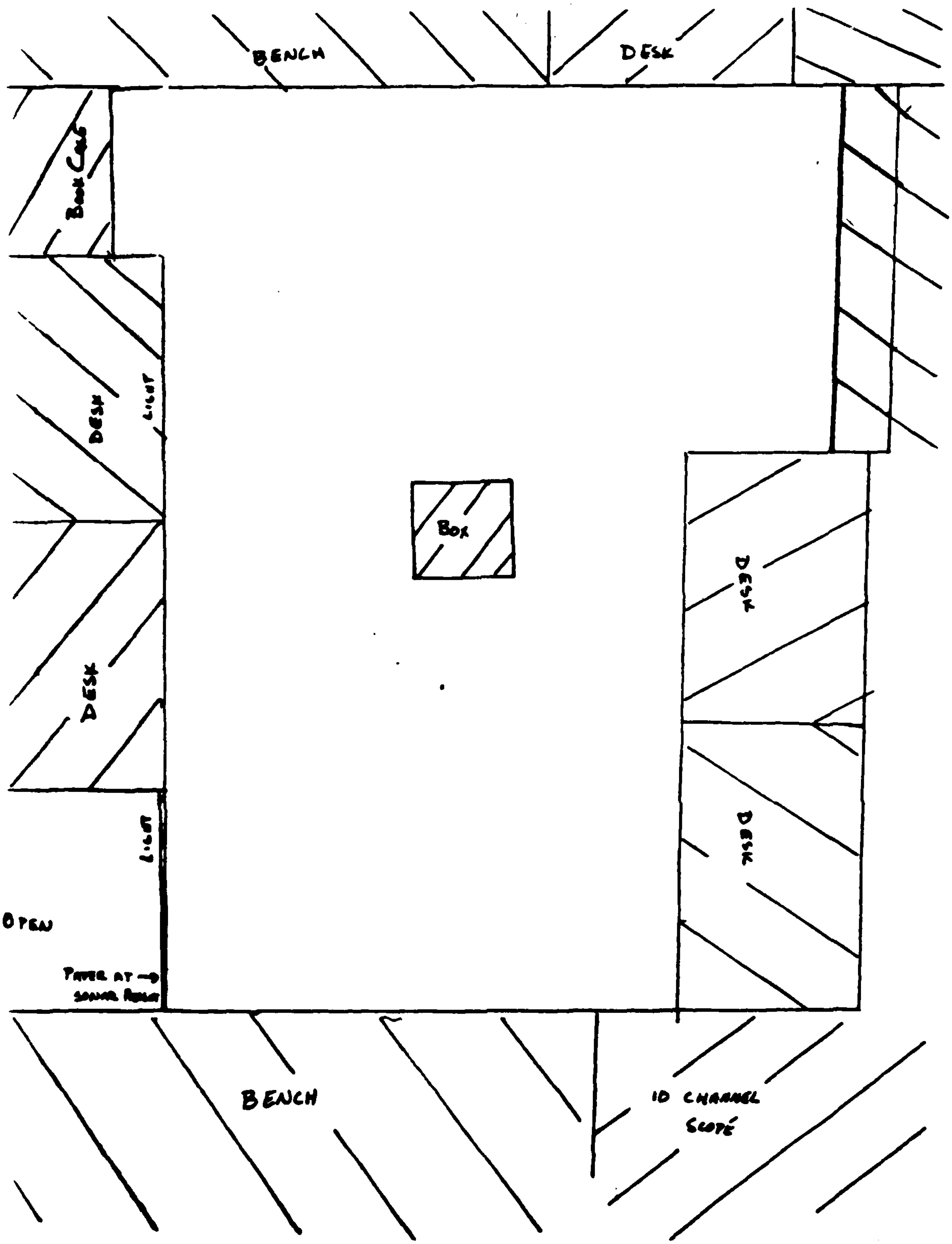

Figure VII-1: Test Area

The run was terminated after about ten minutes. In this time the rover had read eleven different codes with one repeat read. The data gathered appear in table VII-1.

Data Analysis:

The data were plotted by hand (see Figure VII-2). The data grouped nicely around the perimeter and the box in the center of the test area. The plotted area correlates well with the actual test area (see Figure VII-1).

A problem with the resolution of the sonar was noted. As expected, the relatively wide viewing angle of the trancducers lead to an area of uncertainty that gets larger as the distance from the rover increases. The data show an object at a distance accurate to within 0.4 feet, but that object can be anywhere on a 20 degree arc with equal probability.

The box in the center of the test area subtended less than the 20 degree viewing angle from most of the viewing locations. This leads to the additional problem of scattered data near the box's location in the center of Figure VII-2.

Both the angle of uncertainty and central cluttering of the data can be reduced substantially by plotting only the intersections of two or more arcs and ignoring areas covered only by a single return (see Figure VII-3). As can be seen the central clutter is significantly reduced with only a

little reduction in edge definition. This method of examination requires that sufficient data be taken to insure overlapping coverage of the test area.

Location	Range	Location	Range	Location	Range
43	7.8 190deg	50	5.4 180 deg	6C	3.4 320 deg
	5.0		6.2		4.6
	7.8		2.2		7.4
	xx		xx		xx
	8.2		8.6		6.2
	8.2		10.6		10.6
	2.2		3.8		7.4
	7.8		8.6		5.0
46	7.0 170 deg	52	5.8 180 deg	70	4.2 180deg
	5.8		6.2		3.0
	5.8		5.0		5.4
	xx		xx		xx
	8.2		7.0		5.4
	8.2		8.2		6.6
	2.2		5.4		10.6
	2.2		3.4		8.2
4A	7.8 340 deg	64	5.4 195 deg	72	5.8 315 deg
	3.0		5.4		5.4
	4.6		5.4		5.8
	xx		xx		xx
	8.6		8.2		8.2
	11.4		9.8		3.0
	11.4		9.0		3.8
	11.4		5.4		2.2
4D	5.0 350 deg	68	3.0 0 deg		
	2.6		5.4		
	3.4		7.0		
	xx		xx		
	8.2		8.6		
	9.0		8.6		
	2.2		11.4		
	2.2		10.6		

Table VII-1: Mapping Data for Test Area
shown in Figure VII-1

The above data is in feet. The angle is the angle that the scanner beam crossed the code. The zero angle for the test area is parrallel to the bottom edge .

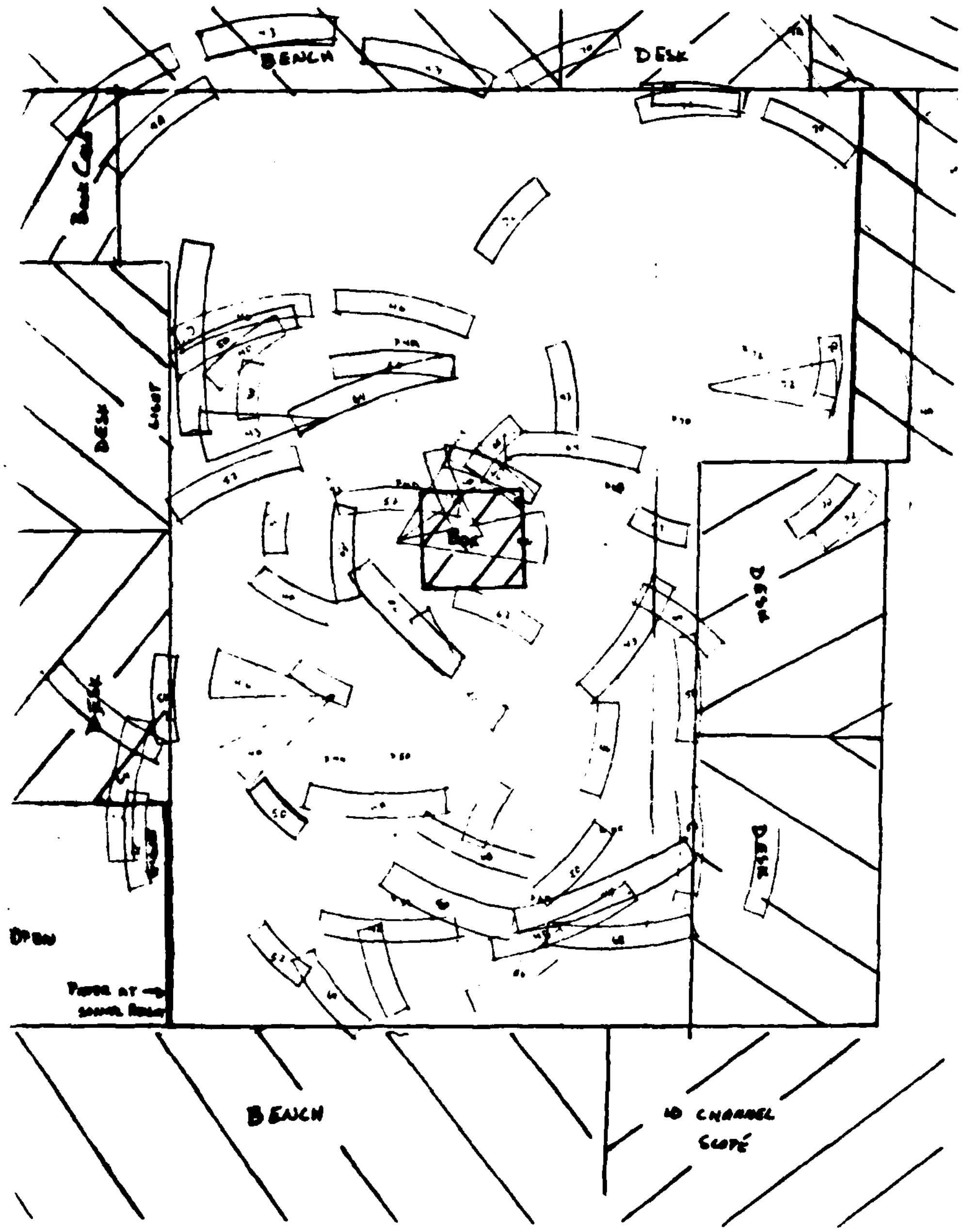

Figure VII-2: Plot of Mapping Data
from Table VII-1

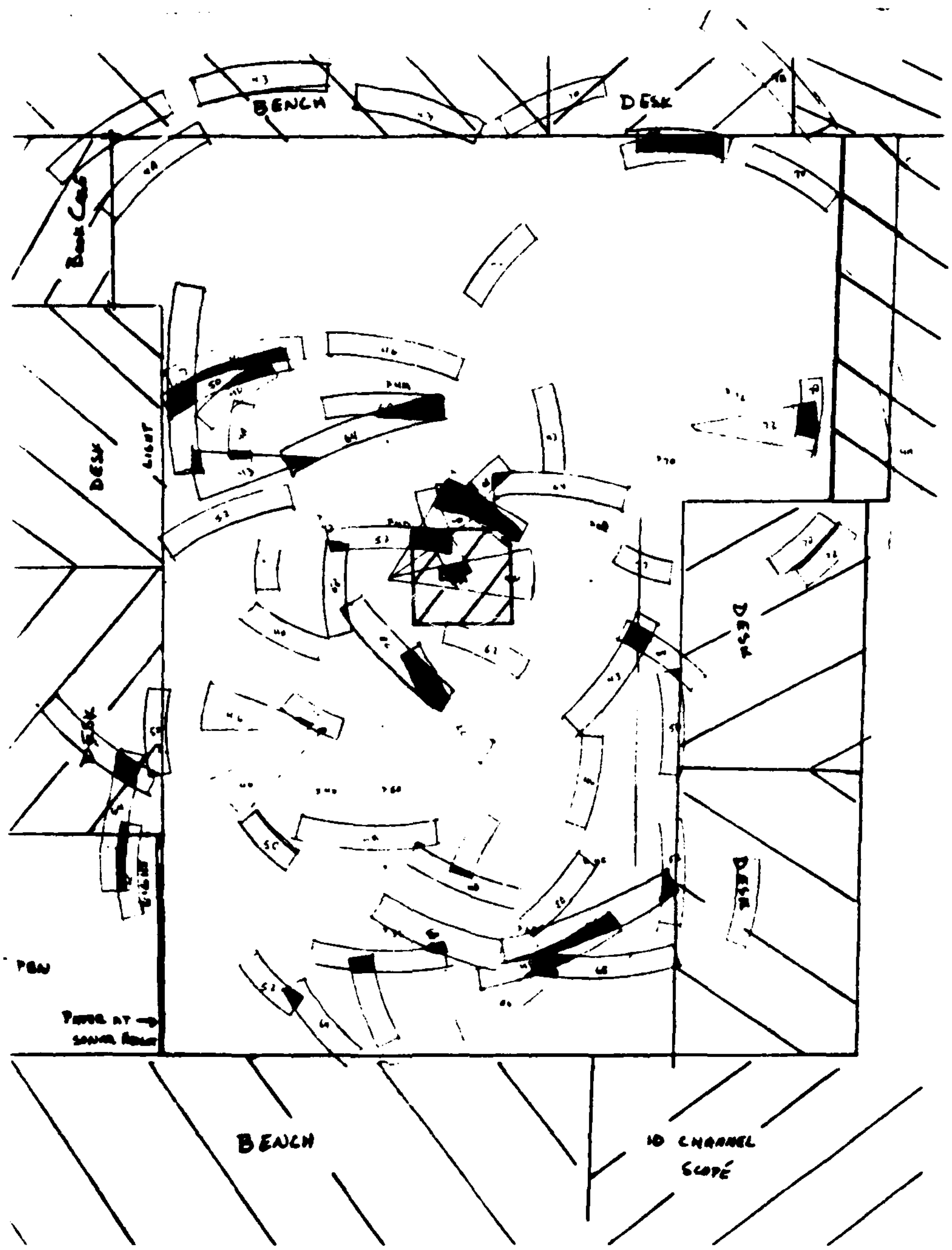

Figure VII-3: Plot of the Intersections of Two or More Arcs of the Mapping Data From Table VII-1

CHAPTER VIII

Recomendations for Future Reasearch:

This thesis is only the first step in the construction of a robotic system capable of performing a complex spatial task such as servicing an aircraft. In order to procede from this point, a number of tasks remain to be accomplished.

The functional robot mapper exibits rudimentary problem solving skills. To fully use its potential, additional software must be developed. To effectively accomplish this several software development tools are required:

1) A 6800 assembler to allow easier programing than the hand assembling performed to date.

2) A robot language utility library consisting of a number of macro commands, for tasks (such as obstacle detection and avoidance, mapper sonar selection, etc.) requiring several lines of code, that can be called in a single line.

3) A 6800 LISP or PASCAL compiler to allow more abstract and complicated programing.

The hardware could also be improved with the addition of:

1) A computer system with a large amount of data storage that can download the rover's programs from disk via the RS-232 port.

2) An FM data link for real time interaction between the rover and a stationary computer system. The stationary system can act either as a peripheral device that processes and archives data for the rover, or as the system controller with the rover as a smart peripheral gathering information for and receiving its instructions from the stationary computer.

3) Additional satellite processors for performance of lower level rover functions (sonar control, communication with laser scanner or stationary computer, location updating, etc.) could free the main processor for faster overall rover control.

4) Experimentation with additional environmental sensors; particularly the phased locked loop IR obstacle detection and phased array sonar systems discussed in chapter 3.

5) Increased power and load carring ability. Presently the rover's load carring and power capacities have been extended to their limits. The initial HERO-1 weighed about 35 pounds, the present system is twice that. This has placed a greater demand on the power supply and has degraded drive and steering motor performance; the steering has become inaccurate and prone to drift and the drive motor stalls when used on low speed. These systems must be redesigned for increased flexibility in future work.

6) Simpler navigation. While it functioned very well, the use of the laser barcode scanner as a navigational device was cumbersome. A system capable of calculating absolute position from some external landmarks (as discussed in chapter 3) or a system capable of keeping track of relative position changes from a known reference (such as optical encoders on the wheels) would be easier to use.

Vita

Randall J. Owen, III was born the son of Barbara B. and Randall J. Owen, Jr on 1 April 1959 in Pittsburgh Pennsylvania. He graduated with honors from Penn Hills High School, Pittsburgh PA, on 11 June 1977. He received an ROTC scholarship, and enrolled at Cornell Universtiy in Ithaca, New York as a freshman in the school of Electrical Engineering in the fall of 1977. Upon graduation, on 31 May 1981, he received his commision in the United States Air Force and was assigned to the Avionics Laboratory of the Air Force Wright Aviation Laboratories at Wright-Patterson Air Force Base, Ohio. He entered the School of Engineering, Air Force Institute of Technology on 2 June 1982.

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Appendix A: Rover Program Assembly Listings

APPENDIX A: ROVER SOFTWARE

The HERO-1 is equipped with a robot language interpreter that is evoked in a program by using the CRL (opcode 3F). The program can also be executed directly in robot language by telling the robot to execute the program using the robot interpreter (using the command string "A, E, starting address" from the keyboard).

The standard 6808 mnemonics do not contain any abbreviations for the robot language commands. To remedy this problem the following will be used:

```
AAM  - Abort Arm Motor
ASM  - Abort Steering Motor
ASP  - Abort SPeech
BAB  - Branch if Arm Busy
BBB  - Branch if Base Busy
BSTB - Branch if STeering Busy
BSPB - Branch if SPeech Busy
CTM  - Change to Machine Language
DD   - Disable Display
DLD  - Disable Light Detector
DMD  - Disable Motion Detector
DSD  - Disable Sound Detector
DUR  - Disable Ultrasonic Ranging
ED   - Enable Display
ELD  - Enable Light Detector
EMD  - Enable Motion Detector
ESD  - Enable Sound Detector
EUR  - Enable Ultrasonic Ranging
MMCA - Move Motor Continue Absolute
MMWA - Move Motor Absolute Wait
MMCR - Move Motor Continue Relative
MMWR - Move Motor Wait Relative
PAUS - Pause
RTE  - Return To Executive
SLP  - SLeeP
SPC  - SPeak Continue
SPW  - SPeak Wait
ZERO - ZERO
```

To further differentiate them from the standard mnemonic

set, they will preceeded by an '*' whenever used in the listing.

ASSEMBLY LISTINGS

Module Name: Interrupt Vector Destinations

Module Function: Sets flag words for both obstacle detection and barcode detection interrupts and reads two digit barcodes for barcode detection interrupt

Label	Address	Mnemonic	Operand /Label	Comment
OBSTINT	0050	LDAA	FF	Load Accumulator with FF
	0052	STAA	OBSTWD	Store FF at Obstacle word
	0054	RTS		Return from subroutine
BARSINT	0060	JSR	TTYIN	Jump to TTYIN to read barcode MSB
	0063	STAA	BARMSB	Store in barcode MSB memory location
	0065	JSR	TTYIN	Read barcode LSB
	0068	STAA	BARLSB	Store in LSB memory location
	006A	LDAA	FF	Load Accumulator with FF
	006C	STAA	BARSWRD	Put FF in Bars Word
	006E	RTS		return from subroutine

Module Name: Vector Initialization

Module Function: Loads the interrupt vector locations in memory so that the obstacle detection and barcode detection interrupts are vectored to OBSTINT and BARSINT respectively. The vectors are located at 002A - 002C for the barcode detection and 002D - 002F for the obstacle detection.

Label	Address	Mnemonic	Operand /Label	Comment
ROVER	0100	LDAA	JMP	Load Accumulator A JMP opcode
	0102	STAA	002A	Store at the first barcode interrupt vector address
	0104	STAA	002D	Store at the first object interrupt vector address
	0106	LDAA	00	Load accumulator with 00
	0108	STAA	002B	Store at the second barcode interrupt vector address
	010A	STAA	002E	Store at the second object interrupt vector address
	010C	LDAA	OBSTINT	Load Accumulator A with the LSB of the obstacle vector
	010E	STAA	002F	Store at the third object interrupt vector address
	0110	LDAA	BARSINT	Load Accumulator A with the LSB of the barcode vector
	0112	STAA	002C	Store at the third barcode interrupt vector address
	0114	JMP	MAPINIT	Jump to Map Init-ialization module

Module Name: Map Initialization

Module Function: Initializes the memory map (B000 - BFFF) by filling the area with zeros.

Label	Address	Mnemonic	Operand /Label	Comment
MAPINIT	0200	LDAA	00	Load 00 into accumulator A
	0202	LDX	B000	Load the index register with the starting address.
ERASE	0205	STAA	00	Store 00 indexed
	0207	INX		Increment Index register
	0208	CPX	BFFF	Compare index register with last memory map address
	020B	BHI	ERASE	If <=, branch to ERASE
	020D	CLR	OBSTWRD	Clear Obstacle word
	0210	LDAA	OSONAR	Load accm. A with the code to turn on the obstacle sonar
	0212	STAA	EXPBD	Store at the experimental port
	0215	JMP	OVRSEER	Jump to Overseerer module

Module Name: Overseerer

Module Function: Checks both interrupt words, if either has been set the proper module is executed. If neither is set the rover is driven forward one unit and the loop repeated.

Label	Address	Mnemonic	Operand /Label	Comment
OVRSEER	0280	CLI		Clear interrupt vector
FORWRD	0281	LDAA	BARSWRD	Load accm. A with the Barcode word
	0283	BNE	GOMAP	If BARSWRD <> 0 branch to GOMAP below
	0285	LDAA	OBSTWRD	Load accm. A with the Obstacle word
	0287	BNE	GOSCAN	If OBSTWRD <> 0 branch to GOSCAN below
	0289	*CRL		Change to robot language
	028A	*MMCA	1001	Move forward one unit, medium speed
	028D	*CTM		change to machine language
	028E	BRA	FORWRD	Branch to FORWRD above
GOSCAN	0290	JSR	AVOID	Jump to obstacle avoidance subroutine
	0293	BRA	OVRSEER	Branch to begining of this module
GOMAP	0295	JSR	INFOSUPR	Jump to Information supervisor sub- routine
	0298	CLR	BARSWRD	Reset barcode word
	029B	BRA	FORWRD	Branch to FORWRD.

Module Name: Obstacle Avoidance

Module Function: Causes the rover to look roughly 30 degrees to both sides. Determines the side with the closest obstacle from the rovers present location and turns the rover in the opposite direction. If there are obstacles too close to both sides, the rover is directed to back up and the entire operation repeated.

Label	Address	Mnemonic	Operand /Label	Comment
AVOID	030C	CLR	OBSTWRD	Clear obstacle word
	030F	LDAA	HEAD#0	Load accm. A with the code for head sonar transducer #1
	0311	STAA	EXPBD	Store at experimental port
	0314	*CRL		Change to Robot language
	0315	*PAUS	0008	Pause 8/16 seconds to give the sonar time to take a distance reading
	0318	*CTM		Change to machine language
	0319	LDAA	EXPBDI	Load the distance to the nearest object on the left of the rover into accmulator A
	031C	LDAB	HEAD#7	Load accm. B with the code for head sonar transducer #7
	031E	STAB	EXPBD	Store at experimental port
	0321	*CRL		Change to Robot language
	0322	*PAUS	0008	Pause 8/16 seconds to give the sonar time to take a distance reading
	0325	*CTM		Change to machine language
	0326	LDAB	EXPBDI	Load the distance to the nearest object on the right of the rover into accmulator B

```
         0329    CBA                 Compare the distance
                                     to the nearest obj.
                                     on both sides of the
                                     rover
         032A    BHI      LEFT       If left range >right
                                     Branch to LEFT
         032C    CMPB     MIN        Compare the right
                                     Range to the minimum
                                     acceptable distance
                                     an obj. can be from
                                     the rover and a turn
                                     initiated
         032E    BHI      RTURN      If object far enough
                                     away branch to right
                                     turn
REV-1    0330    *CRL                Change to robot
                                     language
REVERSE  0331    *MMWA    0C10       Run drive motor
                                     reverse 12 units
                                     slow
         0334    *CTM                Change to machine
                                     language
         0335    BRA      AVOID      Branch to AVOID
LEFT     0337    CMPB     MIN        Compare the left
                                     range to the minimum
                                     acceptable distance
                                     an obj. can be from
                                     the rover and a turn
                                     initiated
         0339    BHI      LTURN      If object far enough
                                     away branch to right
                                     turn
         033B    BRA      REV-1      Branch to one ins-
                                     truction before
                                     REVERSE
LTURN    033D    *CRL                Change to robot
                                     language
         033E    *MMCA    EC00       Turn Steering to 00
         0341    *CML                Change to machine
                                     language
         0342    BRA      GO         Branch to GO
RTURN    0344    *CRL                Change to robot
                                     language
         0345    *MMWA    EC98       Turn steering to 98
GO       0348    *MMWA    1808       Drive forward 8
                                     units fast
         034B    *MMWA    EC49       Center steering
         034E    *CTM                Change to machine
                                     language
         034F    LDAA     OSONAR     Load accm. A with
                                     the code for the
                                     obstacle sonar
         0351    STAA     EXPBDO     Store to experiment
                                     port
```

	0354	RTS		Return from subroutine

Module Name: Information Supervisor

Module Function: Supervision of the barcode conversion from ASCII to hex representation, generation of the memory map, and verification of drive wheel straightness.

Label	Address	Mnemonic	Operand /Label	Comment
INFOSUPR	0400	SEI		Set interrupt mask to prevent interrupt during execution of this module
	0401	CLR	BARSWRD	Clear the bar interrupt word
	0404	JSR	BARS	Jump to the routine tha converts ASCII to hex
	0407	JSR	STRGHT1	Jump to the first part of the wheel realignment routine
	040A	JSR	MAPPER	Jump to the memory map building routine
	040D	JSR	STRGHT2	Jump to the second part of the wheel realignment routine
	0410	LDAA	OSONAR	Load accm. A with the code to turn on the obstacle sonar
	0412	STAA	EXPBDO	Store to the experimental port
	0415	*CRL		Change to robot language
	0416	*MMCA	1812	Drive forward 12 units fast to be sure the scanner is not looking at the barcode just read
	0419	*CTM		Change to machine language
	041A	CLI		Clear interrupt mask
	041B	RTS		Return from subroutine

Module Name: Barcode Reader

Module Function: Barcodes are converted from ASCII to hex representation and manipulated into correct memory word format. The four bytes of the memory word are designated as follows:

[Offset, Barcode MSB, Barcode LSB, Data].

Label	Address	Mnemonic	Operand /Label	Comment
BARS	0505	LDAA	BARMSB	Load the first ASCII character to be converted
	0507	JSR	ASC2HEX	Jump to the ASCII to Hex converter
	050A	ADDA	OFFSET	Add the offset for the location of the memory mapping
	050C	STAA	BARMSB	Store converted and formated code into its memory location
	050E	NOP		
	050F	LDAA	BARLSB	Load the 2nd ASCII character to be converted
	0511	JSR	ASC2HEX	Jump to the ASCII to Hex converter
	0514	ASLA		Multiply by 2
	0515	ASLA		Multiply by 2
	0516	ASLA		Multiply by 2
	0517	ASLA		Multiply by 2
	0518	STAA	BARLSB	Store converted and formatted code into its memory location
	051A	RTS		Return from subroutine

Module Name: TTYIN

Module Function: Input serial data from the RS-232C port.

Label	Address	Mnemonic	Operand /Label	Comment
TTYIN	0600	LDAB	10	Load the code to send the CTS to the scanner to allow it to send data
	0602	STAB	EXPBDO	Store to experiment port
BUSY	0605	LDAB	STATUS	Load the UART status word
	0608	ANDB	DAV	Check if DAV is set (Data is AVailable)
	060A	BEQ	BUSY	If not branch to BUSY
	060C	LDAA	DATA	Load data into accumulator A
	060F	ANDA	7F	Strip parity bit
	0611	LDAB	00	Load accm B. with 00
	0613	STAB	EXPBDO	Store to experiment port to disable CTS
	0616	RTS		Return from subroutine

Module Name: ASCII to Hex Conversion

Module Function: Convert values from ASCII into hexidecimal representation. The ASCII values for 0-9 are 30-39(hex). Therefore, to convert subtract 30(hex). ASCII A-F are 41-46(hex). Therefore 37(hex) must be subtracted.

Label	Address	Mnemonic	Operand /Label	Comment
ASC2HEX	0700	ANDA	7F	Strip parity bit
	0702	CMPA	2F	Compare character to 2F
	0704	BLS	QUIT	If <=, branch to quit because ASCII value does not correspond to a hex character
	0706	CMPA	39(hex)	Compare character to 39(hex)
	0708	BLS	DECIMAL	If <=, then ASCII character is a hex number between 0 and 9
	070A	CMPA	40(hex)	Compare character to 40(hex)
	070C	BLS	QUIT	If <=, branch to quit because ASCII value does not correspond to a hex character
	070E	CMPA	46(hex)	Compare character to 46(hex)
	0710	BHI	QUIT	If >, then ASCII character is not a hex number
	0712	SUBA	07	If the program gets to this point, then the value must be a hex number between A and F. Therefore 37(hex) must be subtracted from the ASCII code, since the next line subtracts 30(hex) only subtract 7 here
DECIMAL	0714	SUBA	30(hex)	Subtract the difference from ASCII and hex #0-9 codes
QUIT	0716	RTS		Return from subroutine

Module Name: Wheel Straightener

Module Function: When operating, the rover's drive wheel orientaion has a tendency to wander. To correct the problem the wheel can be run to the mechanical stop at orientation 00 to reset the angular orientation stored in memory. This module is accessed in two parts, the first part resets the memory word containing the wheel orientation and the second part repoints the wheel straight ahead.

Label	Address	Mnemonic	Operand /Label	Comment
STRGHT1	0800	ROL	WHEEL	multiply the wheel orientation amount by two so that it is definately higher than the actual orientation
	0803	*CTR		Change to Robot language
	0804	*MMCA	EC00	Turn the drive wheel to orientation 00, When the mechanical stop is encountered WHEEL will automatic-ally be reset to 00
	0807	*CTM		Change to machine language
	0808	RTS		Return from subroutine
STRGHT2	0809	*CTR		Change to Robot language
	080A	*MMCA	EC49	Turn the drive wheel to orientation 49, pointing straight
	080D	*CTM		Change to machine language
	080E	RTS		Return from subroutine

Module Name:Map Builder

Module Function: Gather range information from each of the head sonar transducers and store in the first eight words of the map block. Read the light level and sound levels and store them in the ninth and tenth words. Finally the eleventh word, which serves as a counter for how many times that location has been mapped, is incremented.

Label	Address	Mnemonic	Operand /Label	Comment
MAPPER	0900	LDAB	HEAD#0	Load Accm. B with the bit pattern to select the #0 head sonar transducer
	0902	LDX	BARMSB	Load the index register with the two previously adjusted barcode digits stored in BARS1 and BARS2
MAPLOOP	0904	STAB	EXPBDO	Store transducer bit selection pattern to experimental port
	0907	*CTR		Change to robot language
	0908	*ELD		Enable light detector
	0909	*PAUS	0008	Pause 8/16th second
	090C	*CTM		Change to machine language
	090D	LDAA	EXPBDI	Read range
	0910	STAA	MAP	Store (indexed) into memory map
	0912	INX		Increment index reg
	0913	INCB		Increment the bit pattern in accm. B to select the next head sonar transducer
	0914	BMPB	HEAD#7	Compare the code in accm. B to the code for the #7 head sonar transducer
	0916	BLS	MAPLOOP	If <= branch to MAPLOOP
	0918	LDAA	LIGHT	Read light sensor
	091B	STAA	MAP	Store (indexed) into memory map
	091D	INX		Increment index register

091E	*CTR		Change :o robot lang.
091F	*DLD		Disable light detector
0920	*ESD		Enable Sound dector
0921	*CTM		Change to machine language
0922	LDAA	SOUND	Read light sensor
0925	STAA	MAP	Store (indexed) into memory map
0927	INX		Increment index register
0928	INC		This location tells how many times this coordinate has been mapped

Appendix B: Bar Code Printing Program

```
1   REM ****************************************************
        *   NAME: BARS2.BAS                                 *
3   REM *   AUTHOR: LT RANDALL J. OWEN                      *
        *   DATE: JUNE 1983                                 *
5   REM *                                                   *
        *   THIS PROGRAM PRINTS TWO DIGIT BARCODES          *
        *   INCREMENTALLY FROM 00 TO FF                     *
7   REM *   RUNNING ON THE CROMEMCO SYSTEMS UNDER MBASIC    *
        *   USING THE ANADEX PRINTER.  AFTER RUNNING, THE   *
        *   FORM FEED FUNCTION IS DISABLED AND THE PRINTER  *
9 REM   *   MUST BE RESET.                                  *
        *                                                   *
        *   TO CHANGE CODE WIDTH, CHANGE THE VARIBLE "WIDTH"  *
11 REM  *   IN LINE 15.                                     *
        *                                                   *
13 REM ****************************************************

15 WIDTH = 500
20 Y=0 :REM                 *INITIALIZE Y & Z TO ZERO
30 Z=0
50 A=-1   : REM             *INITIALIZE 'A' SO THAT FIRST BAR
                             PATTERN  PRINTED IS A START/STOP
                             (S/S) CHARACTER.
55 GOSUB 900 :REM           *GO TO OUTPUT SUBROUTINE AND PRINT
                             S/S PATTERN
60 IF Y>=16 GOTO 9999 :REM  *TEST FOR STOP CONDITION
90 A=Y :REM                 *SET A=Y SO THAT 'Y' PATTERN IS
                             PRINTED
95 DIGIT=1 :REM             *SET DIGIT SO THAT PRINT SUBROUTINE
                             RECOGNIZES VALUE AS THE MSB FOR
                             LABELING
100 GOXSUB 1000 :REM        *GOTO OUTPUT SUBROUTINE AND PRINT MSB
110 A=Z :REM                *SET A=Y SO THAT  'Z'  PATTERN  IS
                             PRINTED
115 DIGIT=0 :REM            *SET DIGIT SO THAT PRINT SUBROUTINE
                             RECOGNIZES THE VALUE AS THE LSB FOR
                             LABELING
120 GOSUB 1000 :REM         *GOTO OUTPUT SUBROUTINE AND PRINT LSB
130 A=-1 :REM               *SET A TO PRINT THE S/S PATTERN
135 GOSUB 900 :REM          *GOTO OUTPUT SUBROUTINE AND PRINT THE
                             S/S PATTERN
140 LPRINT B$;" ";C$; :REM  *PRINT THE HEXIDECIMAL TWO DIGIT VALUE
                             OF THE CODE
150 FOR X=0 TO 17 :REM      *IN GRAPHICS MODE THE PRINTER'S FF IS
                             DISABLED, THESE COMMANDS FEED THE
                             APPROPRIATE NUMBER OF LFS TO
                             ACCOMPLISH A FORM FEED
155 LPRINT CHR$(10)
157 NEXT X
158 LPRINT CHR$(28);"@3"
160 Z=Z+1 :REM              *INCREMENT LSB
170 IF  Z>=16 THEN Z=0:  Y=Y+1 :REM *IF LSB =16 THEN SET LSB=0
                                     AND INCREMENT MSB
190 GOTO 50
```

```
900 IF A<>-1 GOTO 1000 :REM *CHECK FOR A SET FOR S/S PATTERN
910 BAR$="0100101000" :REM  *SET BAR$ SO THAT PRINT ROUTINE
                             PRINTS S/S PATTERN
920 GOSUB 2000 :REM         *GOTO PRINT ROUTINE
929 REM
930 REM ***********************************************************
        * THE FOLLOWING SECTION OF CODE EXAMINES THE VALUE    *
        * OF 'A' AND SETS BAR$ WITH THE CORRECT BIT PATTERN  *
        * TO PRINT THE CORRECT BAR PATTERN AND SETS 'B$'     *
        * & 'C$' ARE USED IN LINE 140 TO PRINT THE LABEL.    *
934 REM ***********************************************************

1000 IF A<>0 GOTO 1050
1010 BAR$="0001101000"
1020 IF DIGIT=1 THEN B$="0"
1030 IF DIGIT=0 THEN C$="0"
1040 GOSUB 2000
1050 IF A<>1 GOTO 1100
1060 BAR$="1001000010"
1070 IF DIGIT=1 THEN B$="1"
1080 IF DIGIT=0 THEN C$="1"
1090 GOSUB 2000
1100 IF A<>2 GOTO 1150
1110 BAR$="0011000010"
1120 IF DIGIT=1 THEN B$="2"
1130 IF DIGIT=0 THEN C$="2"
1140 GOSUB 2000
1150 IF A<>3 GOTO 1200
1160 BAR$="1011000000"
1170 IF DIGIT=1 THEN B$="3"
1180 IF DIGIT=0 THEN C$="3"
1190 GOSUB 2000
1200 IF A<>4 GOTO 1250
1210 BAR$="0001100010"
1220 IF DIGIT=1 THEN B$="4"
1230 IF DIGIT=0 THEN C$="4"
1240 GOSUB 2000
1250 IF A<>5 GOTO 1300
1260 BAR$="1001100000"
1270 IF DIGIT=1 THEN B$="5"
1280 IF DIGIT=0 THEN C$="5"
1290 GOSUB 2000
1300 IF A<>6 GOTO 1350
1310 BAR$="0011100000"
1320 IF DIGIT=1 THEN B$="6"
1330 IF DIGIT=0 THEN C$="6"
1340 GOSUB 2000
1350 IF A<>7 GOTO 1400
1360 BAR$="0001001010"
1370 IF DIGIT=1 THEN B$="7"
1380 IF DIGIT=0 THEN C$="7"
1390 GOSUB 2000
1400 IF A<>8 GOTO 1450
1410 BAR$="1001001000"
1420 IF DIGIT=1 THEN B$="8"
```

```
1430 IF DIGIT=0 THEN C$="8"
1440 GOSUB 2000
1450 IF A<>9 GOTO 1500
1460 BAR$="0011001000"
1470 IF DIGIT=1 THEN B$="9"
1480 IF DIGIT=0 THEN C$="9"
1490 GOSUB 2000
1500 IF A<>10 GOTO 1550
1510 BAR$="1000010010"
1520 IF DIGIT=1 THEN B$="A"
1530 IF DIGIT=0 THEN C$="A"
1540 GOSUB 2000
1550 IF A<>11 GOTO 1600
1560 BAR$="0010010010"
1570 IF DIGIT=1 THEN B$="B"
1580 IF DIGIT=0 THEN C$="B"
1590 GOSUB 2000
1600 IF A<>12 GOTO 1650
1610 BAR$="1010010000"
1620 IF DIGIT=1 THEN B$="C"
1630 IF DIGIT=0 THEN C$="C"
1640 GOSUB 2000
1650 IF A <>13 GOTO 1700
1660 BAR$="0000110010"
1670 IF DIGIT=1 THEN B$="D"
1680 IF DIGIT=0 THEN C$="D"
1690 GOSUB 2000
1700 IF A<>14 GOTO 1750
1710 BAR$="1000110000"
1720 IF DIGIT=1 THEN B$="E"
1730 IF DIGIT=0 THEN C$="E"
1740 GOSUB 2000
1750 IF A<>15 GOTO 1800
1760 BAR$="0010110000"
1770 IF DIGIT=1 THEN B$="F"
1780 IF DIGIT=0 THEN C$="F"
1790 GOSUB 2000
1800 IF A>15 THEN LPRINT "ERROR IN 1800, A="A;
1810 RETURN
1900 REM ***********************************************************
1920 REM * THE FOLLOWING SECTION OF CODE PARSES THE STRING     *
         * 'BAR$' INTO TWO TWO DIGIT PIECES WHICH ARE THEN     *
         * USED TO PRINT A BAR/SAPCE PAIR.  THE FIRST DIGIT    *
1950 REM * DETERMINES THE BAR WIDTH AND THE SECOND             *
         * DETERMINES THE SPACE WIDTH WITH A '1' MEANING A     *
         * WIDE CHARACTER AND A '0' A THIN CHARACTER.          *
1970 REM *                                                     *
         *******************************************************

2000 FOR I = 1 TO 9 STEP 2 :REM *READS BAR$ TWO BITS AT A TIME
2020 CODE$=MID$(BAR$,I,2)
2025 REM LPRINT CHR$(28)
2030 IF CODE$="10" THEN GOSUB 3000
2040 IF CODE$="00" THEN GOSUB 3500
2050 IF CODE$="11" THEN GOSUB 4000
```

```
2060 IF CODE$="01" THEN GOSUB 4500
2070 NEXT I
2080 LPRINT CHR$(29) :REM        *TAKES PRINTER OUT OF GRAPHICS
                                  MODE
2090 RETURN

2850 REM ***************************************************
2900 REM *           PRINT A FAT BAR AND THIN SPACE        *
2950 REM ***************************************************
3000 COUNT=0
3005 LPRINT CHR$(28)
3010 FOR COUNT=0 TO WIDTH
3020 LPRINT CHR$(127)
3030 NEXT COUNT
3040 LPRINT "@6"


3350 REM ***************************************************
3400 REM *         PRINT A THIN BAR AND A THIN SPACE       *
3450 REM ***************************************************
3500 COUNT=0
3505 LPRINT CHR$(28)
3510 FOR COUNT=0 TO WIDTH
3520 LPRINT CHR$(127);
3530 NEXT COUNT
3540 LPRINT "@6"
3550 LPRINT "@6"
3560 RETURN

3850 REM ***************************************************
3900 REM *         PRINT A FAT BAR AND FAT SPACE           *
3950 REM ***************************************************
4000 COUNT=0
4005 LPRINT CHR$(28)
4010 FOR COUNT=0 TO WIDTH
4020 LPRINT CHR$(127);
4030 NEXT COUNT
4040 LPRINT "@6"

4350 REM ***************************************************
4400 REM *        PRINT A THIN BAR AND FAT SPACE           *
4450 REM ***************************************************
4500 COUNT=0
4505 LPRINT CHR$(28)
4510 FOR COUNT=0 TO WIDTH
4520 LPRINT CHR$(127);
4530 NEXT COUNT
4540 LPRINT "@6"
4550 LPRINT "@6"
4560 LPRINT "@6"
4570 RETURN

9999 END
```

Appendix C: Bar Code 3 Of 9

AUTOMATIC IDENTIFICATION MANUFACTURERS UNIFORM SYMBOL DESCRIPTION—3 CODE 39©

1. Introduction and History

This document and its associated series is written by the member companies of the Automatic Identification Manufacturers, a product section of The Material Handling Institute, Inc. Each Uniform Symbol Description (USD) will describe one bar code symbol and its corresponding encodation. The symbol descriptions are numbered sequentially starting with one. For example, AIM, USD-1. Associated with each AIM USD number will be any industry names or trademarks for the symbol.

The AIM, USD-3 symbol otherwise referred to as CODE 39, is a bar code with a full alphanumeric character set, a unique start and stop character, and seven other characters. The name CODE 39 is derived from its code structure which is 3 wide elements out of a total of 9 elements (an element is the area occupied by a bar or space). The nine elements consist of five bars and four spaces. This structure 3 of 9, was named CODE 39.

2.0 Symbol Encodation

The symbol uses a series of wide and narrow elements to represent each character. These wide or narrow elements can be represented by either a bar or a space. The wide elements are equal to a binary value of one (1), while the narrow elements are equal to a binary value of zero (0). Each character has a unique binary representation and element pattern. The specific structure of each character in AIM, USD-3 is given in Table 1.

CODE 39 is a trademark of Interface Mechanisms, Inc.

Table 1: Character Structure, USD-3

CHAR.	PATTERN	BARS	SPACES	CHAR.	PATTERN	BARS	SPACES
1		10001	0100	M		11000	0001
2		01001	0100	N		00101	0001
3		11000	0100	O		10100	0001
4		00101	0100	P		01100	0001
5		10100	0100	Q		00011	0001
6		01100	0100	R		10010	0001
7		00011	0100	S		01010	0001
8		10010	0100	T		00110	0001
9		01010	0100	U		10001	1000
0		00110	0100	V		01001	1000
A		10001	0010	W		11000	1000
B		01001	0010	X		00101	1000
C		11000	0010	Y		10100	1000
D		00101	0010	Z		01100	1000
E		10100	0010	.		00011	1000
F		01100	0010	-		10010	1000
G		00011	0010	SPACE		01010	1000
H		10010	0010	•		00110	1000
I		01010	0010	$		00000	1110
J		00110	0010	/		00000	1101
K		10001	0001	+		00000	1011
L		01001	0001	%		00000	0111

• Denotes a start/stop code which must precede and follow every bar code message. Note that • is used only for the start/stop code.

The Start/Stop Character is a unique character used to identify the leading and trailing end of the bar code symbol. See Figure 1. The Start/Stop Character must be included in every bar code symbol. It precedes the most significant character and follows the least significant character. The structure of the Start/Stop Character allows symbols to be scanned bidirectionally.

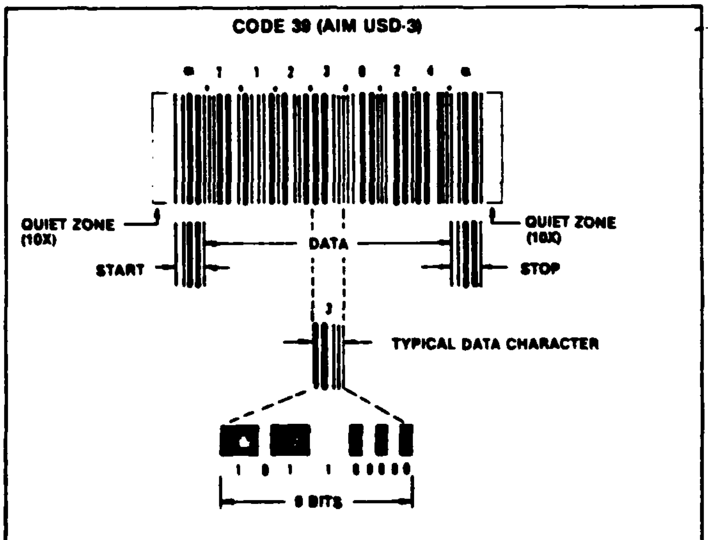

FIGURE 1

3.0 Quiet Zone

The Quiet Zone is an area that is clear and free of all printing preceding the Start Character and following the Stop Character. The minimum Quiet Zone dimension is ten times (10 X) the nominal narrow element (x). See Figure 1.

4.0 Wide To Narrow Ratio

The ratio of dimensions between wide elements (bars or spaces) and the narrow elements (bars or spaces) is referred to as the wide to narrow ratio.

The dimension of the narrow bars and narrow spaces is called the X dimension. All X dimensions must be equal in a symbol. The dimension of the wide bars and spaces is a multiple of X. The ratio is preselected and must be maintained throughout the printed symbol.

If the X dimension is 0.020 inch or larger, the AIM, USD-3 can be printed with wide to narrow ratios from 2:1 through 3:1. If the X dimension is less than 0.020 inch, the AIM USD-3 must be printed with wide to narrow ratios from 2.2:1 through 3:1. See Figure 2.

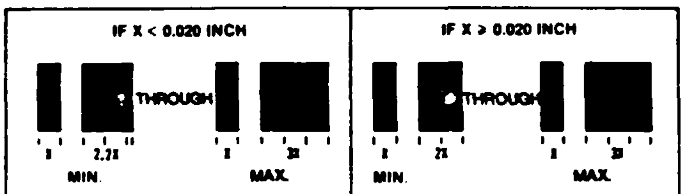

FIGURE 2 WIDE TO NARROW RATIO

5.0 Intercharacter Gap

The intercharacter gap is the space between two adjacent characters. The minimum width of the intercharacter gap is the X dimension (the narrow element width). The maximum width of the intercharacter gap is 9X. See Figure 3.

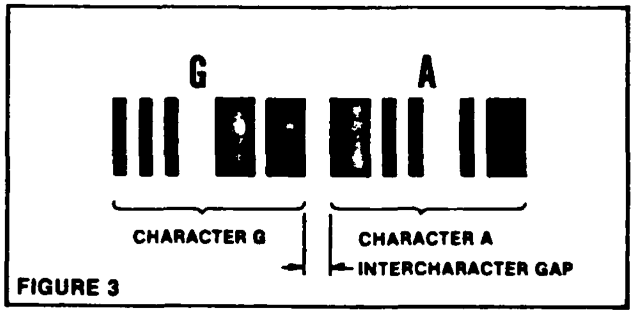

FIGURE 3

6.0 Check Digit

None

7.0 Characters Per Symbol

Variable length symbols may be mixed in a system. For example, most scanners can read symbols ranging from one data character to 30 data characters.

AUTOMATIC
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A PRODUCT SECTION OF
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5/81 5M

Appendix D: Polaroid Sonar Data Sheets

ULTRASONIC RANGING SYSTEM

Description, operation and use information for conducting tests and experiments with Polaroid's Ultrasonic Ranging System components.

Polaroid

TABLE OF CONTENTS

POLAROID ULTRASONIC RANGING UNIT

Introduction

The purpose of this manual is to familiarize you with the Polaroid Ultrasonic Ranging Unit. It is intended to provide enough detai so that you can easily conduct tests and experiments with this device to determine its suitability to your needs.

This kit is intended for experimental use only.

The first section of this manual is a brief overview of the major components of the system and their function. The second section contains the information you will need to operate and interface with this device. In addition, typical waveforms, timing diagrams, schematics and characteristic graphs are included.

Section three describes the experimental demonstration board included in this kit. This board will enable you to immediately begin your evaluation of the ranging unit with a minimum of effort.

At the end of this manual, you will find technical specification sheets, information request forms, and order forms. We at Polaroid look forward to your continued interest in our ultrasonic products as well as the other Polaroid products included in this kit.

Please note that components other than the ultrasonic transducer are not for sale at this time.

This kit comes complete with:

(1) 2-Polaroid Instrument-Grade Electrostatic Transducers
(2) 1-Polaroid Ultrasonic Circuit Board (modified)
(3) 1-Experimental Demonstration Board
(4) 1-Polaroid Circular Polarizer
(5) 2-Polaroid Polapulse Batteries
(6) 1-Polapulse Battery Holder
(7) Assorted Connectors and Wires

For additional information or technical assistance write:

Polaroid Corporation
Ultrasonic Ranging Marketing
Cambridge, Massachusetts 02139

Or call toll free from the continental U.S.:
800-225-1618

In Massachusetts call collect: 617-547-5177

I - GENERAL DESCRIPTION

Two primary components comprise the Polaroid Ultrasonic Ranging Unit; they are an acoustical transducer and ultrasonic circuit board (Figure 1).

Together these components are capable of detecting the presence and distance of objects within a range of approximately 0.9 feet to 35 feet. In operation, a pulse is transmitted toward a target and the resulting echo is detected. The elapsed time between initial transmission and echo detection can then be converted to distance with respect to the speed of sound. For a transmitted pulse to leave the transducer, strike a target two feet away, and to return to the transducer, requires an average time lapse of 3.55 milliseconds (or 1.78 milliseconds per foot – round trip).

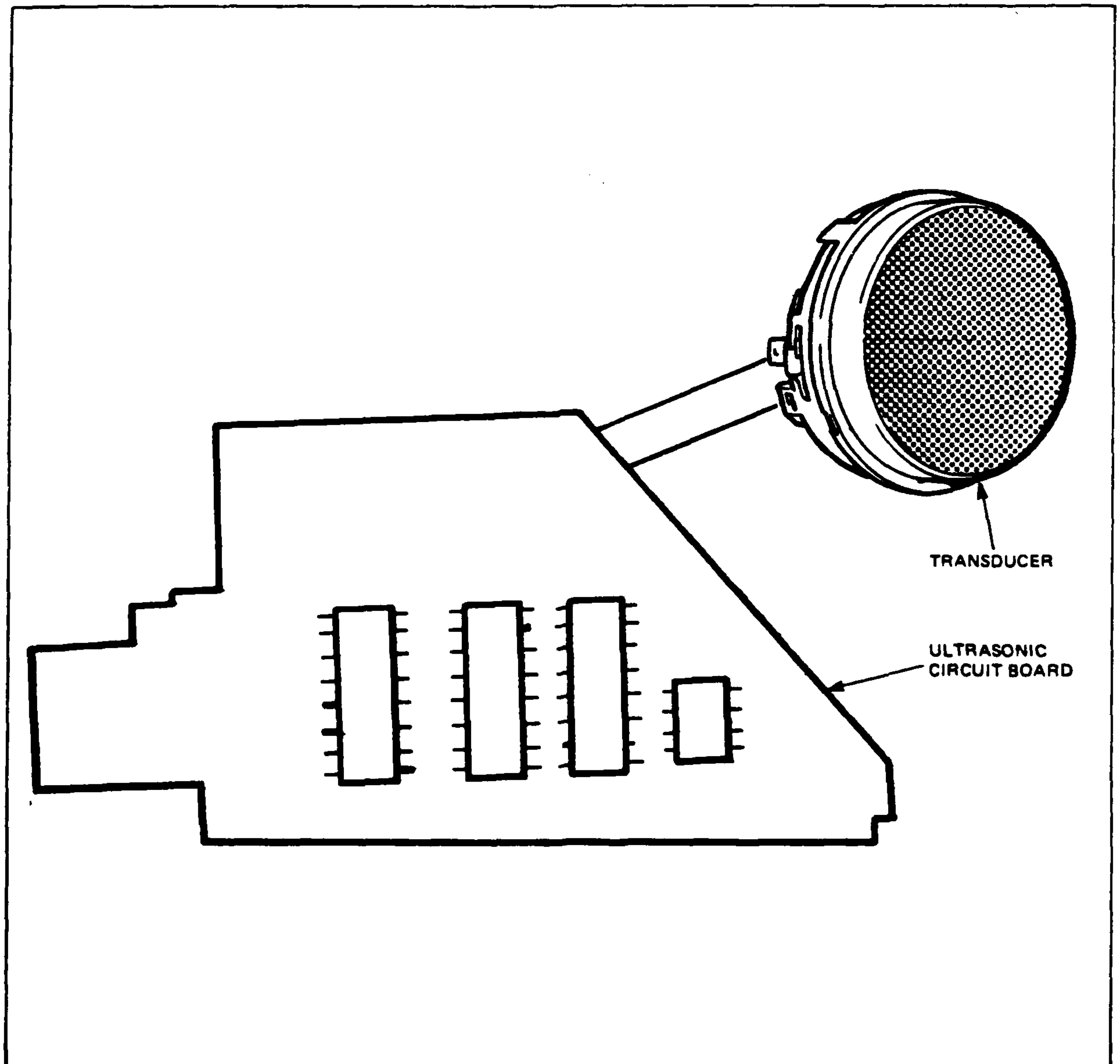


FIGURE 1. BLOCK DIAGRAM – ULTRASONIC CIRCUIT BOARD/TRANSDUCER

The principal component in this device is the transducer (Figure 2), which acts as both loudspeaker and microphone. It has been designed to transmit the outgoing signal and also to function as an electrostatic microphone in order to receive the reflected signal (the echo). Its diameter determines the acoustical lobe pattern, or acceptance angle, during the transmit and receive operation. A special, Polaroid manufactured foil is stretched over a grooved plate, forming the moving element which transforms electrical energy into sound waves and the returning echo back into electrical energy. The grooved, metallic backplate in contact with the foil forms a capacitor which, when charged, exerts an electrostatic force to the foil. The foil is pliable, capable of resisting harsh environments, and an excellent electrical conductor.

NOTE: *Polaroid Corporation offers two grades of electrostatic transducers for sale; Instrument Grade and Commercial Grade. The Instrument Grade transducer is included in this kit to meet the performance demand of the ultrasonic circuit board to range between 0.9 feet and 35 feet. If your application is less demanding, or different from our technique of distance ranging, the Commercial Grade transducer may be more appropriate. Please be aware that the ultrasonic circuit board, as described in this manual, is not guaranteed to operate reliably with anything but Polaroid's Instrument Grade electrostatic transducer.*

Under no circumstances should the user attempt to rebuild the transducer as this will change its acoustical characteristics.

WARNING: **Be certain that the transducer is properly connected to the ultrasonic circuit board before applying power. Applying power to the board with the transducer disconnected may damage the board.**

When the unit is activated, the transducer emits a sound pulse, then waits to receive the echo returning from whatever object the sound pulse has struck. The emitted pulse is a high-frequency, inaudible "chirp," lasting for one millisecond and consisting of fifty-six pulses at four carefully-chosen, ultrasonic frequencies: 60 kHz, 57 kHz, 53 kHz and 50 kHz. Occasionally, a single frequency could be cancelled because of certain target topographical characteristics, and no echo would be reflected. This device uses four frequencies to overcome that possibility.

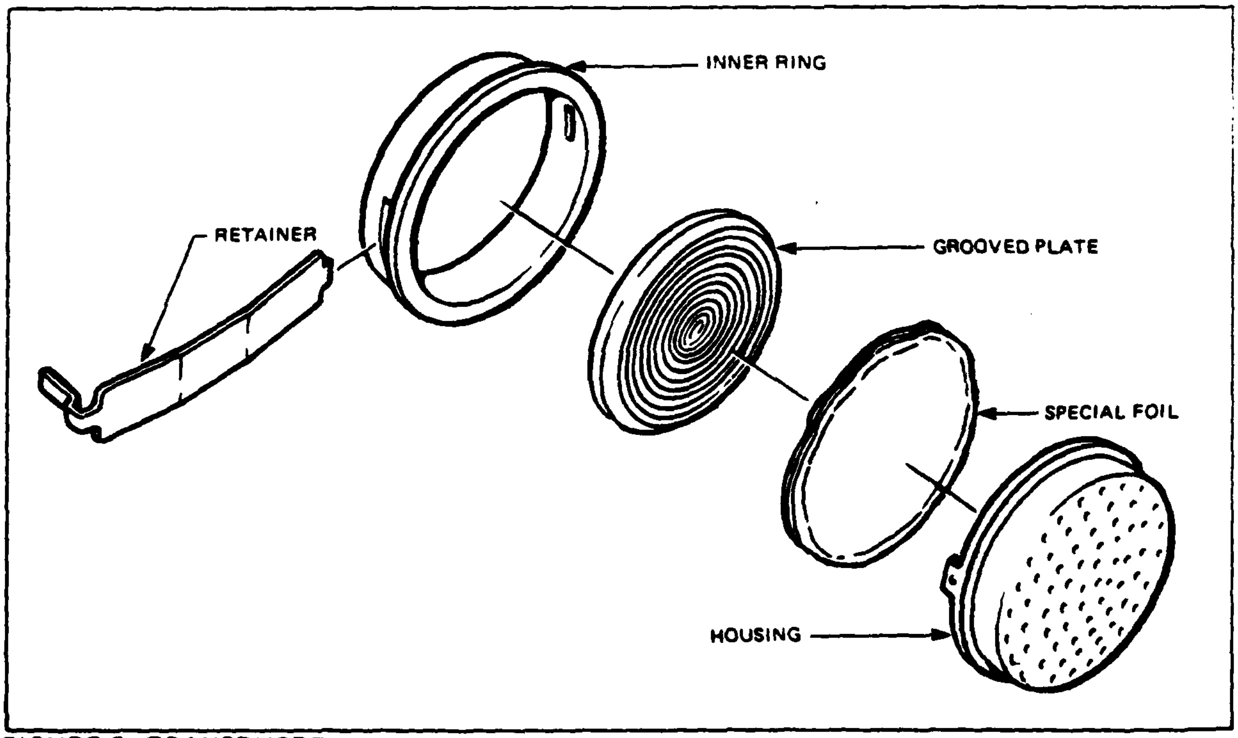


FIGURE 2. TRANSDUCER

The ultrasonic circuit board electronics (Figure 3) control the operating mode (transmit/receive) of the transducer. It is comprised of three major sections, which control transducer operation and allow the information gathered by it to be used as desired. Among the sections are: a digital circuit, an analog circuit and a power section.

NOTE: Although the Dual PNP section is present, it is not used in any of the circuits described in this book.

Powered by a 6 VDC supply, capable of 1 ms current surges of at least 2.5 AMPS, an appropriate drive circuit initiates the transmission of an ultrasonic pulse by the transducer (Figure 4). (Several drive circuits are described later in this book.)

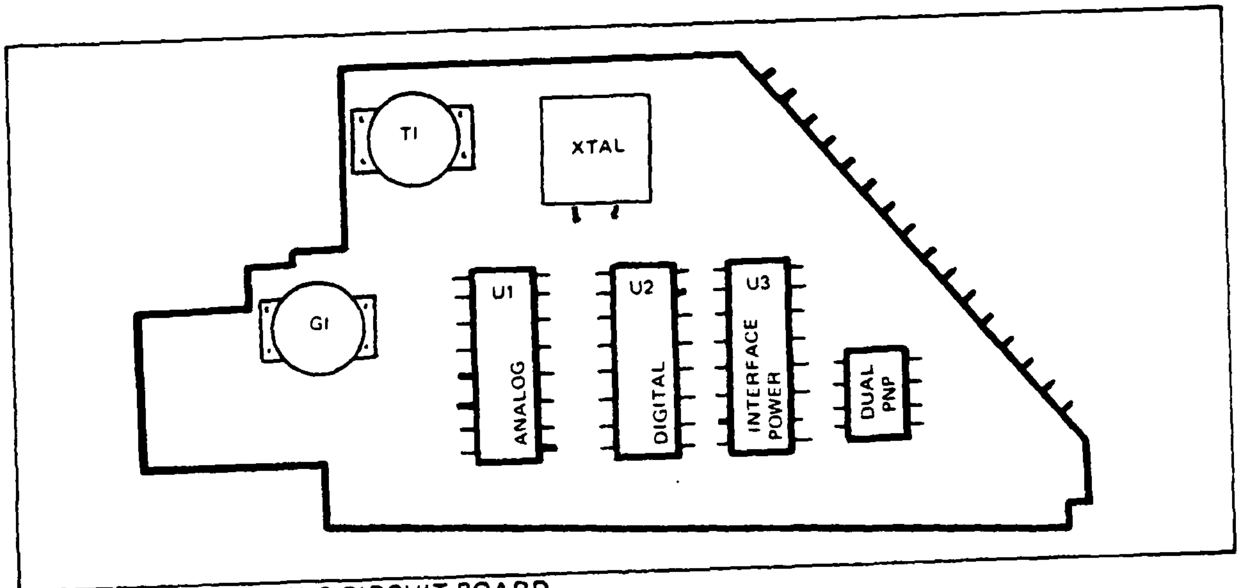


FIGURE 3. ULTRASONIC CIRCUIT BOARD

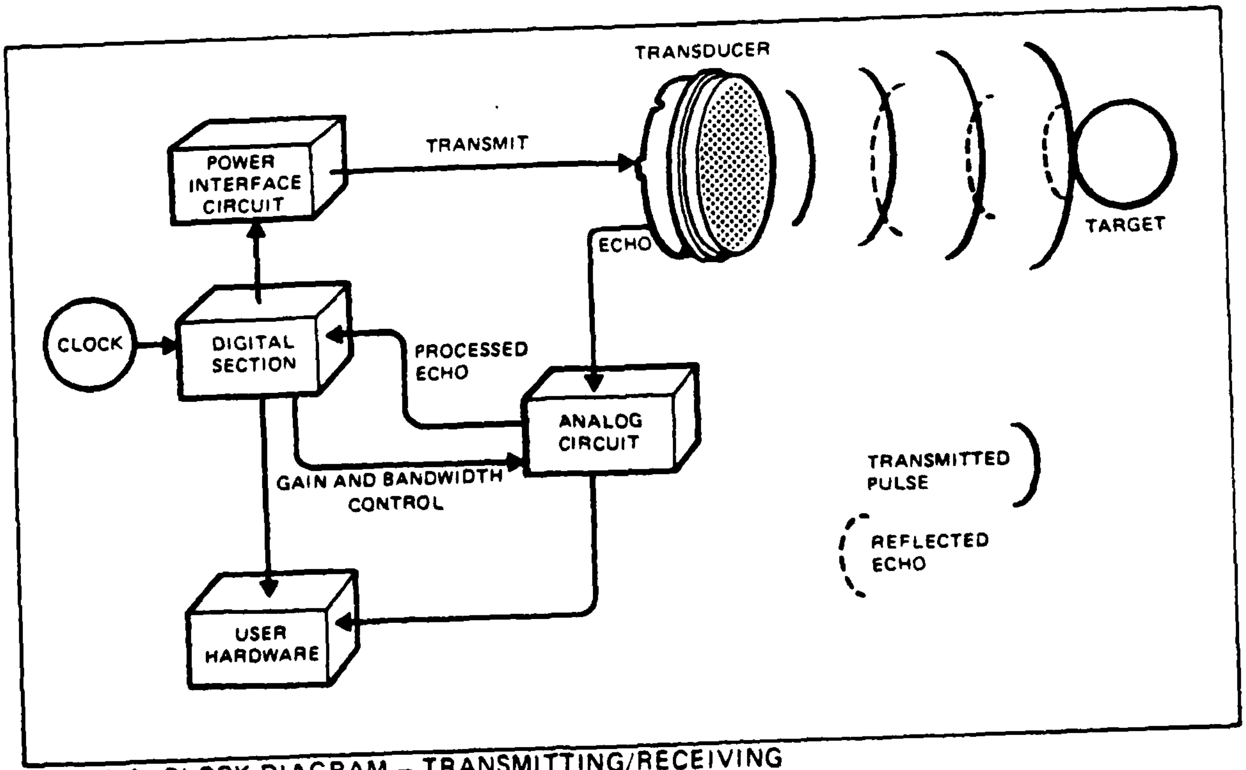


FIGURE 4. BLOCK DIAGRAM – TRANSMITTING/RECEIVING

A crystal-controlled clock in the digital circuit generates the ultrasonic frequencies that comprise the pulse transmitted by the transducer.

After generating the "chirp," the operating mode of the transducer changes, in effect, from loudspeaker to microphone to detect the returning echo. Upon receiving the echo, the transducer converts the sound energy to electrical energy, which is amplified by the analog circuit, then detected by the digital circuit to produce the echo received signal.

WARNING: **A 300 volt signal is applied across the transducer each time a "chirp" is transmitted. Anyone contacting this signal during transmission will feel a noticeable, but harmless, shock.**

Because of the reduction in return signal strength (echo) over longer distances (return signal power at 35 feet is almost a million times weaker than at 3 feet), a dual role is played by the amplifier within the analog circuit. In addition to processing the echo, the amplifier also performs the function of maintaining a tailored sensitivity over the entire operating range (distance covered) of the system. Lower amplification is needed for close echoes, while higher amplification is needed for distant echoes. The change in amplification is accomplished by increasing the gain and the Q of the amplifier in eight steps, out to 13.3 feet, and then by increasing just the gain of the amplifier, again in eight steps, beyond 13.3 feet. As you may see, a tailored sensitivity over the entire operating range is important and necessary.

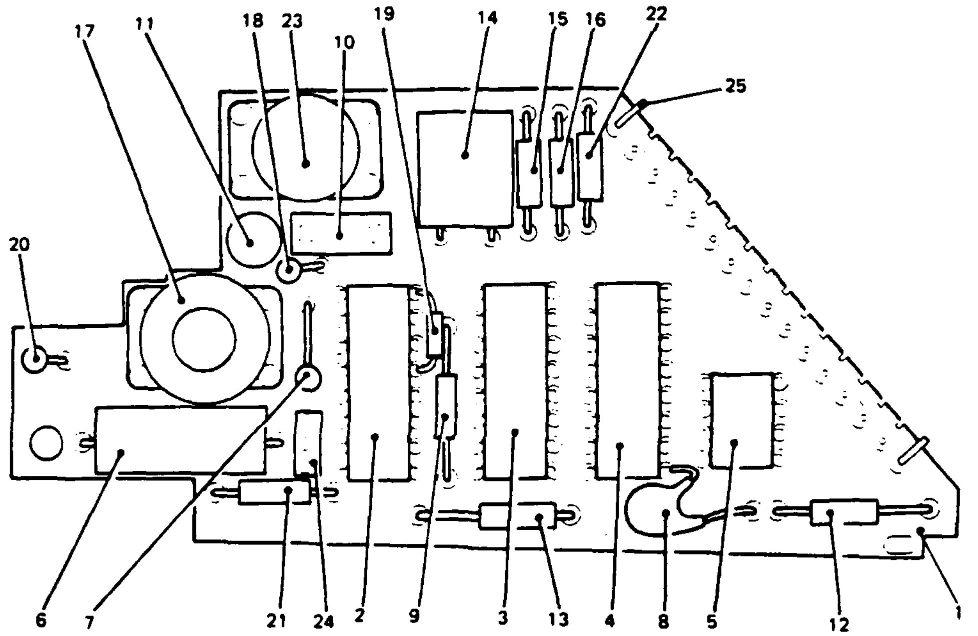
NOTE: The overall gain can be adjusted with potentiometer R6 (24, Fig. 5). Excessive gain may cause a false receive indication just after transmit; insufficient gain may cause intermittent, far-field detection. These conditions, created by differences among Polaroid Instrument Grade Transducers, should be corrected by adjusting R6.

With this brief description as a base, pertinent operating details will now be presented as an aid in using the system and in establishing and monitoring its performance.

II - USING THE POLAROID ULTRASONIC RANGING UNIT

Following are suggested circuits and circuit-board modifications that enable the Ranging Unit to be examined and used in various ways. Bear in mind that **these are only suggestions** to help you get started. There may be other ways to adapt this module to your needs; however, these circuits will allow immediate use of this device for your evaluation.

Figures 5 and 6 are component-layout and schematic diagrams respectively. Refer to these figures to familiarize yourself with the circuit boards.



ITEM	REF.	DESCRIPTION
1		PC BOARD
2	U1	ANALOG DIP
3	U2	DIGITAL DIP
4	U3	INTERFACE DIP
5	U4	DUAL (PNP) DIP
6	C1	CAPACITOR .01μf, 10V
7	C2	CAPACITOR .01μf, 50V
8	C3	CAPACITOR 1μf, 35V
9	C4	CAPACITOR .001μ, 10V
10	C5	CAPACITOR .0022μf, 400V
11	C6	OMITTED
12	C7	CAPACITOR .1μf, 50V
13	C8	CAPACITOR .01μf, 10V

ITEM	REF.	DESCRIPTION
14	XTAL	CRYSTAL
15	CR1	DIODE ZENER (IN990B)
16	CR2	DIODE ZENER (IN990B)
17	L1	TUNED CIRCUIT INDUCTOR
18	R1	RESISTOR ¼W (SEE NOTE 1)
19	C9	CAPACITOR .01μf, 50V
20	R3	RESISTOR (75 K, CF, ±5% ¼W)
21	R4	RESISTOR (75 K, CF, ±5% ¼W)
22	R5	RESISTOR (30 K, CF, ±5% ¼W)
23	T1	TRANSFORMER
24	R6	RESISTOR VARIABLE
25		PIN, MALE (SEE NOTE 2)

NOTE 1: RESISTOR VALUE SET AT FACTORY.
NOTE 2: FITS BERG 47217 CONNECTOR.

FIGURE 5. COMPONENT LAYOUT

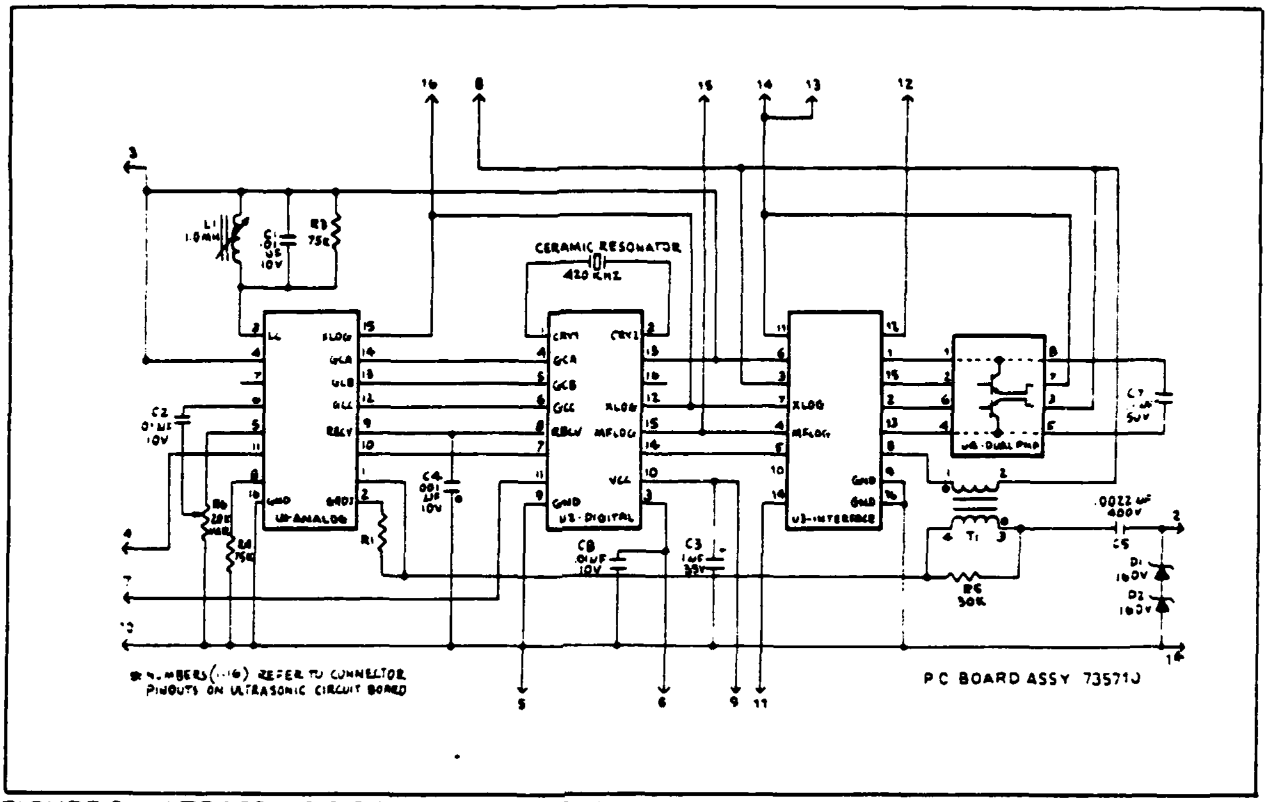


FIGURE 6. ULTRASONIC CIRCUIT BOARD SCHEMATIC (MODIFIED)

A. WAVEFORMS

The waveforms (Figure 7) presented here illustrate the pertinent timing relationships. These waveforms apply to a circuit board modified as shown in Figure 8.

1. Power (VSW)

Circuit power is obtained as shown in Figure 8. A 6 VDC. 2.5 AMP power supply is required. Power for all circuits described in this manual can be obtained from the Polapulse Batteries provided in the kit. Simply insert a battery into the battery holder (Figure 9),and connect your chosen circuit to the appropriate terminals.

WARNING: Be certain that the transducer is properly connected to the ultrasonic circuit board before applying power. Applying power to the board with the transducer disconnected may damage the board.

A multiple drive logic signal, MDL, initiates a transmit/receive cycle by supplying the ultrasonic circuit board with the VSW signal (Figure 7). For proper operation. MDL should be high for 100 ms and low for a minimum of 100 ms.

NOTE: Production of drive signal MDL will be described in Part C of this section of this book. Timing relationships should not be established with respect to this signal, because the transmit signal (XLG, para. 2 below) does not start at a time that is precisely repeatable after the application of power.

Components in the VSW circuit, identified with an asterisk (*), comprise a speed-up circuit to allow rapid cycling. With the speed-up circuit, off-time can be as short as 40 ms. If rapid cycling is not desired, those components identified with an asterisk (*) can be omitted.

2. Transmission (XLG)

XLG (Figure 7) is the digital logic drive for the transmitted signal. It consists of eight cycles at 60 kHz, eight cycles at 57 kHz, sixteen cycles at 53 kHz and twenty-four cycles at 50 kHz for a total of fifty-six cycles and lasts for a period of about 1 millisecond. All timing relationships between transmitted signals and received echos are determined from the leading edge of this signal.

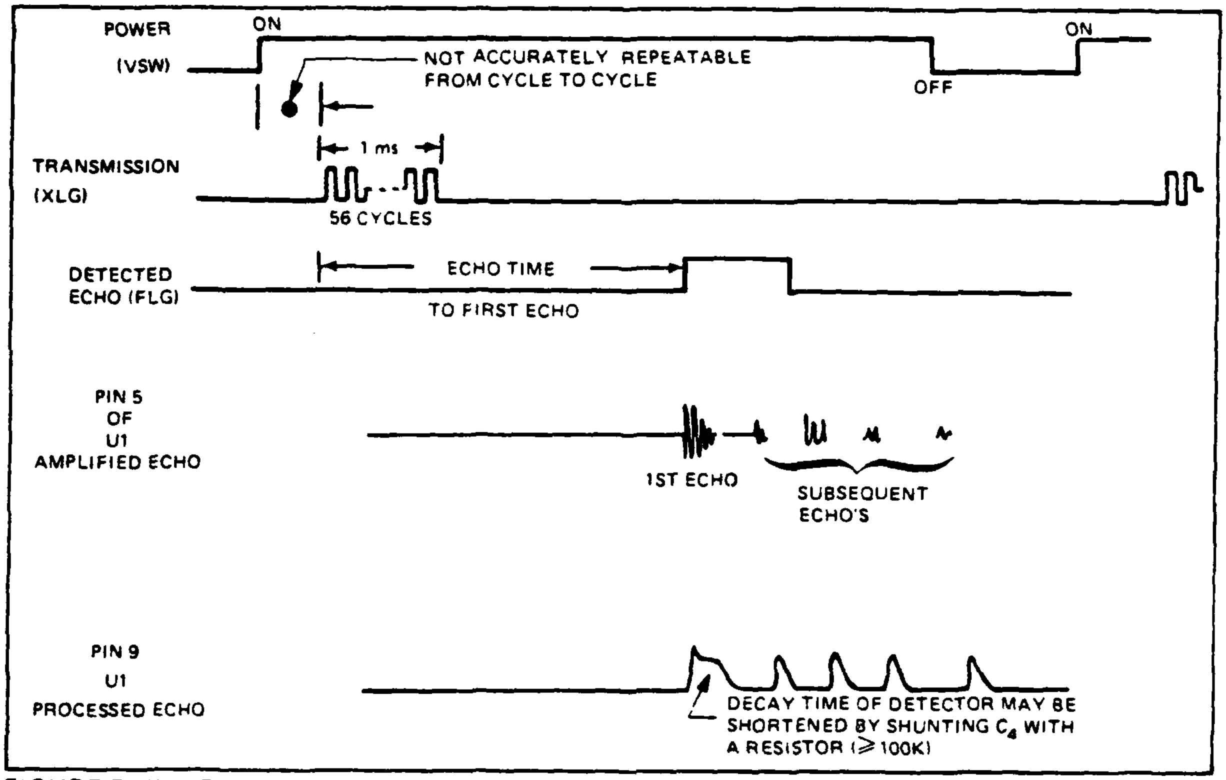


FIGURE 7. WAVEFORMS

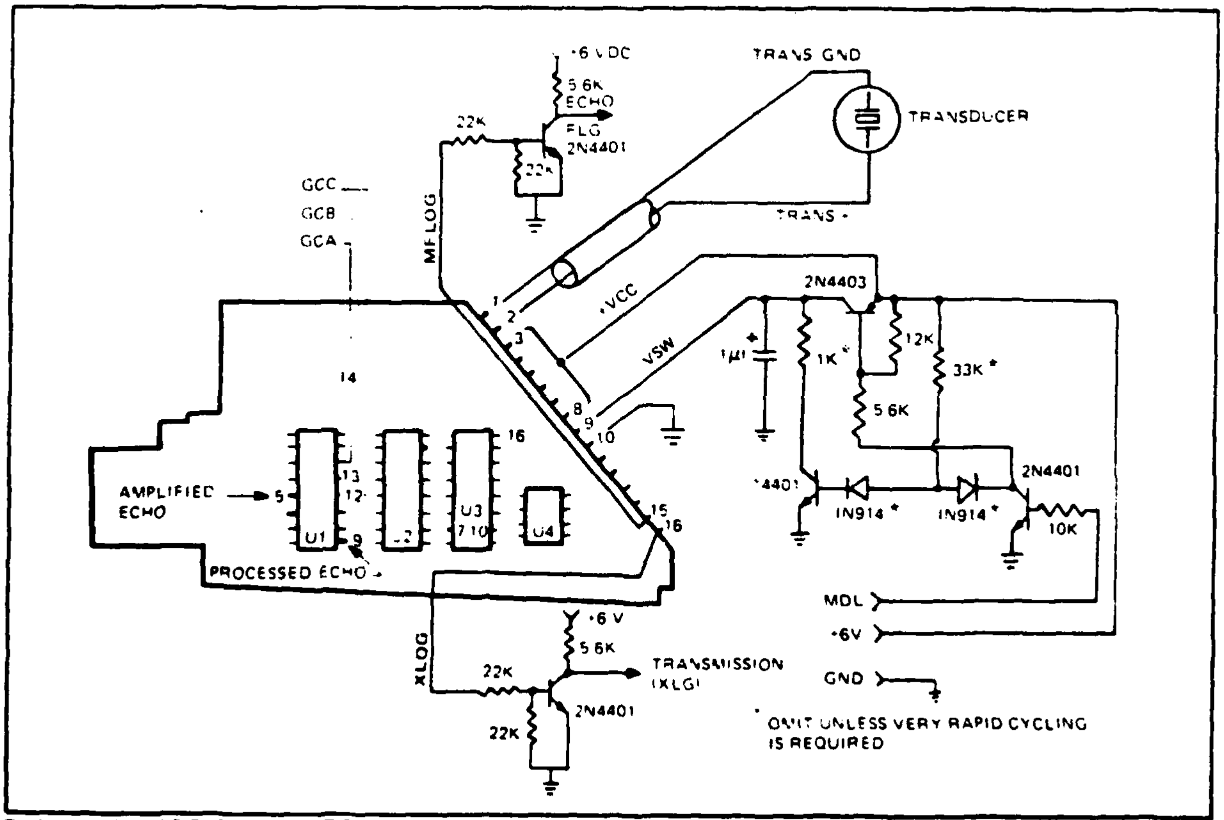


FIGURE 8. MODIFIED ULTRASONIC CIRCUIT BOARD

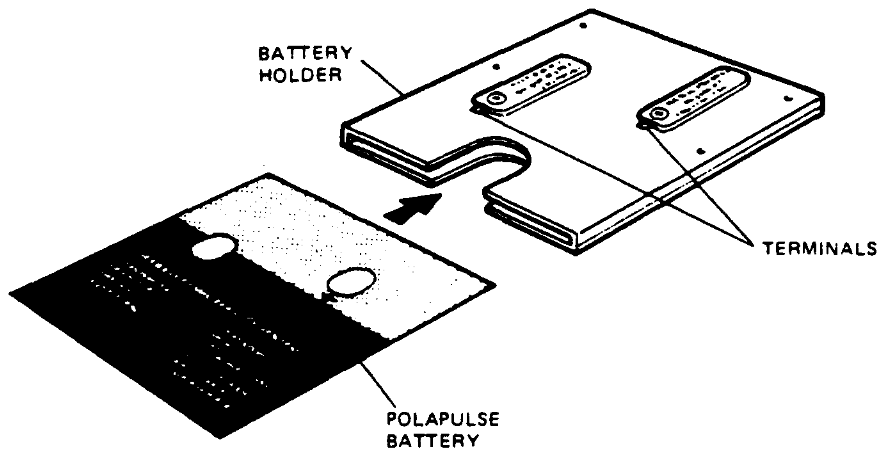


FIGURE 9. POLAPULSE BATTERY AND HOLDER

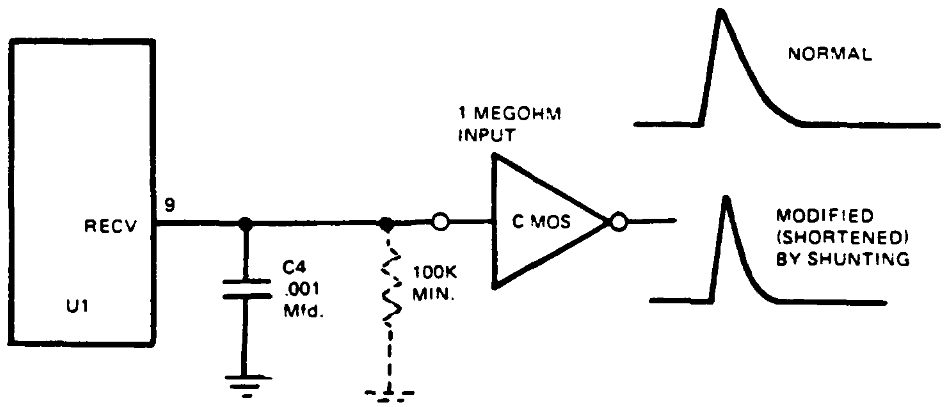


FIGURE 10. MODIFIED ECHO DETECTOR

The interface circuit for extracting this signal is shown at the bottom of Figure 8. The input signal for this circuit is obtained at terminal 16 of the ultrasonic circuit board.

3. Amplified Echo

The amplified echo (Figure 7) can be observed at pin 5 of U1 (Figure 8). This signal is useful for observing the reflected echos. Echos below detector threshold may also be viewed here. Normally this signal would not be extracted; however, this is the place to look when adjusting the gain of the module.

4. Processed Echo

The processed echo (Figure 7) can be observed at pin 9 of U1 as shown in Figure 8. The decay ti of this signal may be shortened by shunting ca citor C4 with a resistor of at least 100k ohms. MOS circuits (Figure 10), or circuits of at least o megohm input impedance, provide a convenier way to extract this signal, if desired. This signa is useful if echos, other than the first echo, are interest.

5. Detected Echo (FLG)

FLG (Figure 7) is the signal which indicates th the echo (the reflected transmission signal) ha been received. It is obtained from terminal 15 the ultrasonic circuit board. The interface circ for extracting FLG is shown at the top of Figı and is identical with that used for XLG.

B. GAIN CONTROLLING LOGIC

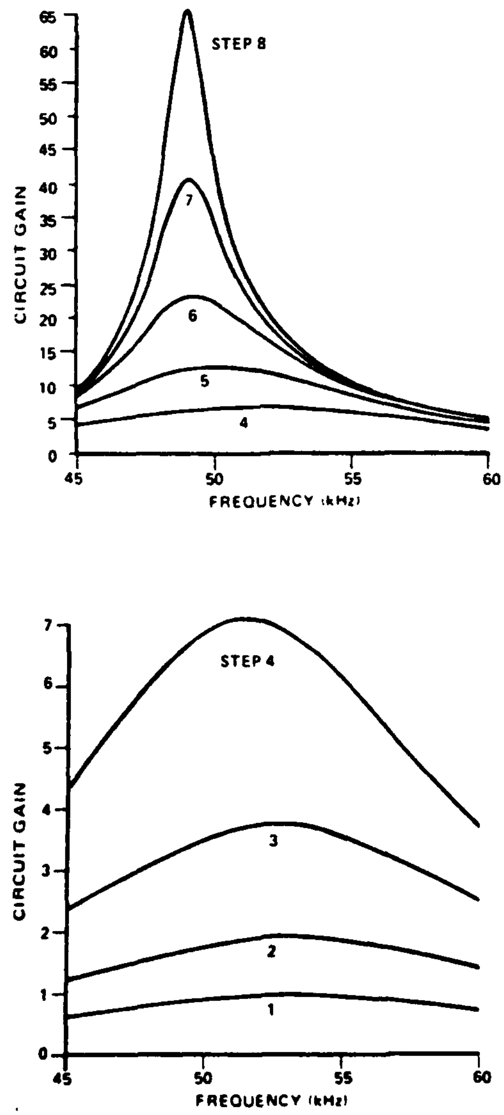
Three logic signals control the system gain and bandwidth as a function of time. The timing and performance relationships between the logic signals, gain and bandwidth are shown in Figure 12.

The gain controlling logic can be observed at the following points (Figure 8):

GCA at pin 14 of U1
GCB at pin 13 of U1
GCC at pin 12 of U1

Interface circuits, identical to those used for FLG and XLG, can also be used for these gain signals. Gain changes can be made by changing resistor R1 on the circuit board (Figure 5) and by adjusting potentiometer R6.

NOTE: The bandwidth changes continuously with time in eight steps, but is continuously narrow for the second eight steps and centered at about 50 kHz (see Figure 11).



***NOTE:** *Only the graphs of the first eight gain steps are included here for clarity. Steps 9-16 are identical to step 8 except that each successive step is increased in gain by 4 db.*
These graphs are generated from theoretical information, not experimental data.

FIGURE 11. POLAROID ULTRASONIC RANGING UNIT GAIN VS. FREQUENCY*

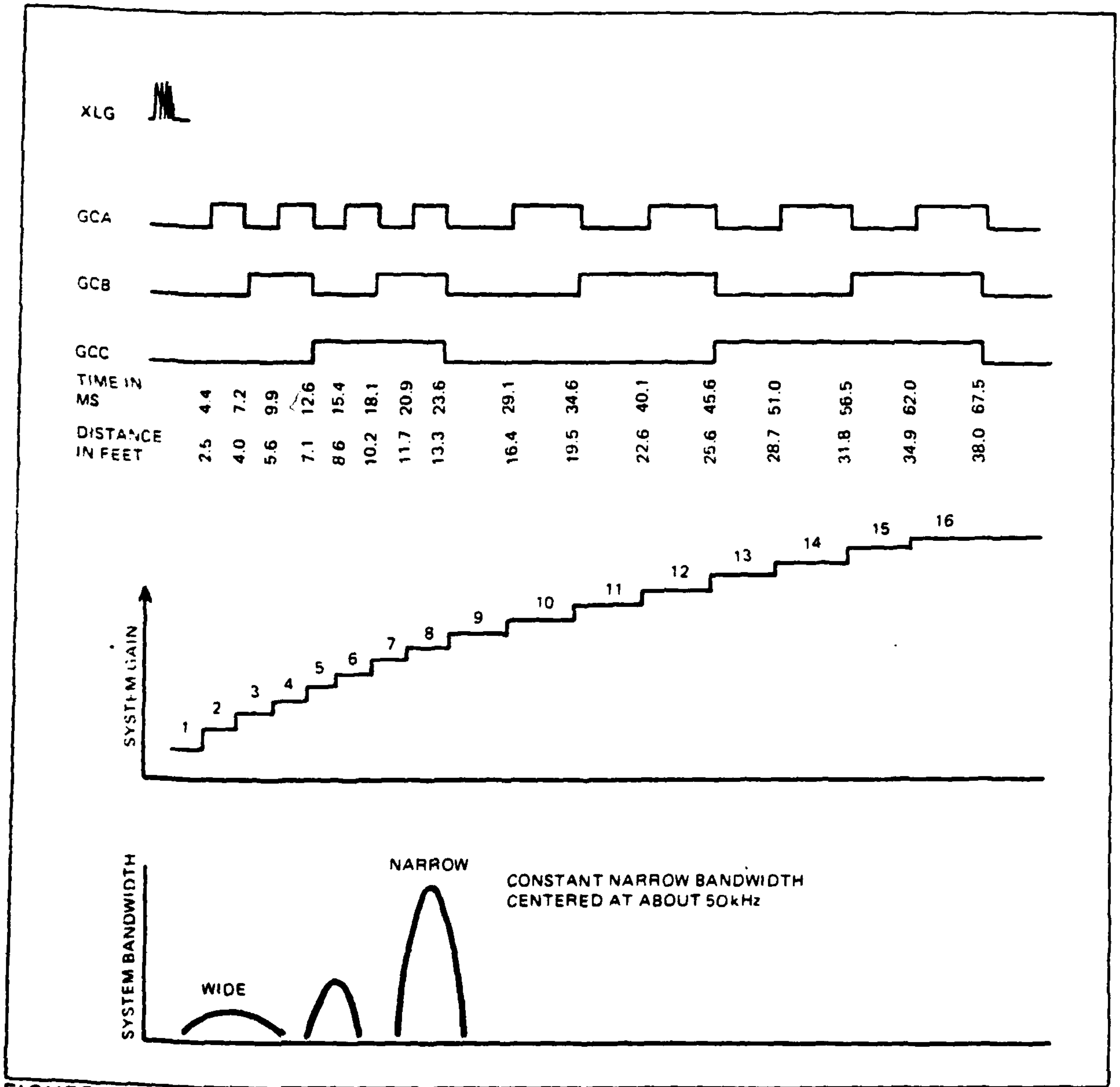


FIGURE 12. GAIN CONTROLLING LOGIC

C. SUGGESTED DRIVE CIRCUITS

As mentioned in part A.1. of this section, the production of drive signal MDL will be discussed here. Although there may be other methods for driving the ultrasonic unit, these circuit configurations have been tested and found to perform well while being simple to construct. In addition, they will enable you to quickly use and evaluate the ultrasonic unit.

The primary component in the following configurations are C-MOS devices (74C14 hex Schmitt triggers) which work quite well as drive circuits.

Figure 13 is a symmetrical drive, suitable for generating one-to-five repetitions per second (rps).

Both pulse duration and off-time are approximately equal to $T \cong RC$.

Figure 14 is an asymmetrical drive, capable of providing up to 10 rps with long "on" symmetry. As above, pulse duration is approximately equal to $T_1 \cong R_1 C$; however, off-time is equal to approximately:

$$T_2 \cong \frac{R_1 R_2}{R_1 + R_2} \times C.$$

Figure 15 is also an asymmetrical drive; however, it is designed to provide as little as 4 repetitions

per minute with long "off" symmetry. Pulse duration is approximately equal to:

$$T_1 \cong \frac{R_1 R_2}{R_1+R_2} \times C;$$

off time is approximately equal to $T_2 \cong R_1 C$.

Figure 16 is included here for its application value rather than as a general drive circuit. It is a method of cycling several systems in sequence repeatedly so that they do not interfere with each other.

This circuit is a digital system utilizing a symmetrical drive. (All components are identified on the drawing.) Very slow repetition rates can be achieved with this circuit, and it can be used to drive up to eight modules in sequential order.

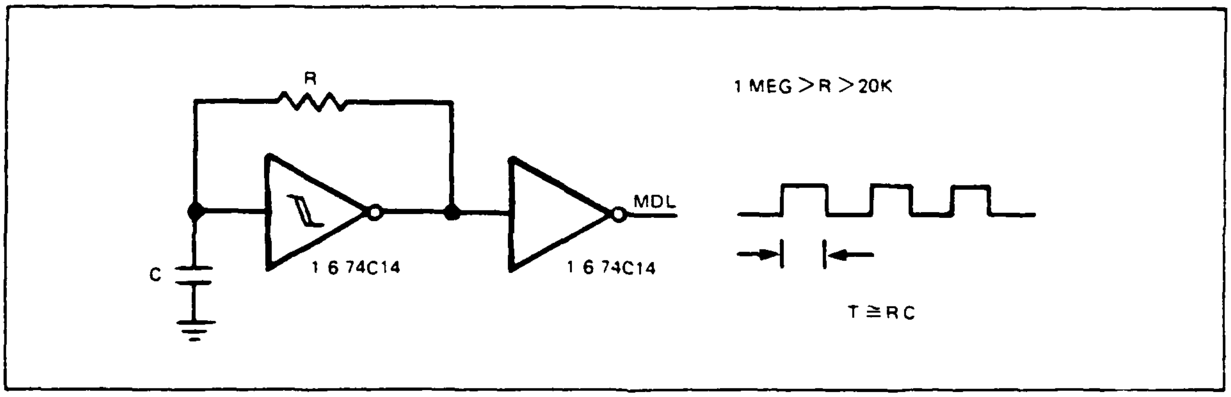


FIGURE 13. SYMMETRICAL DRIVE

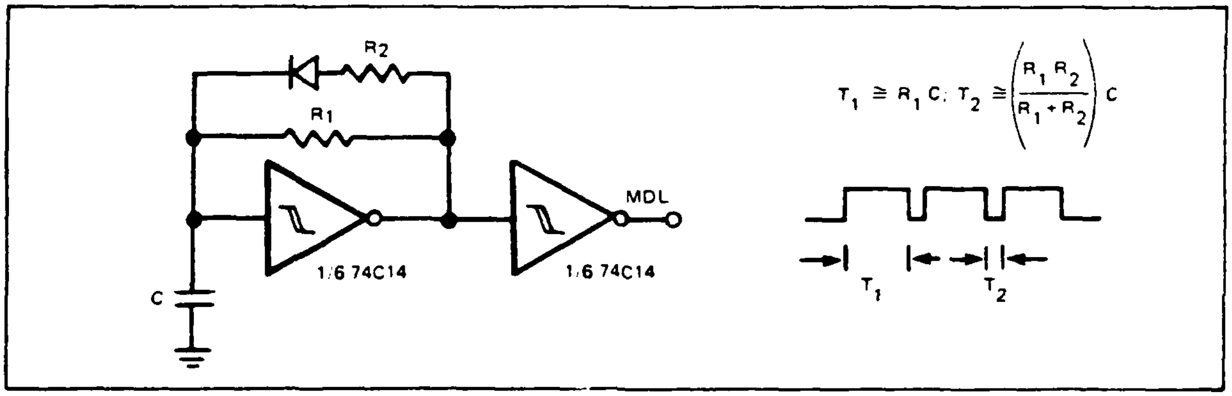


FIGURE 14. ASYMMETRICAL DRIVE

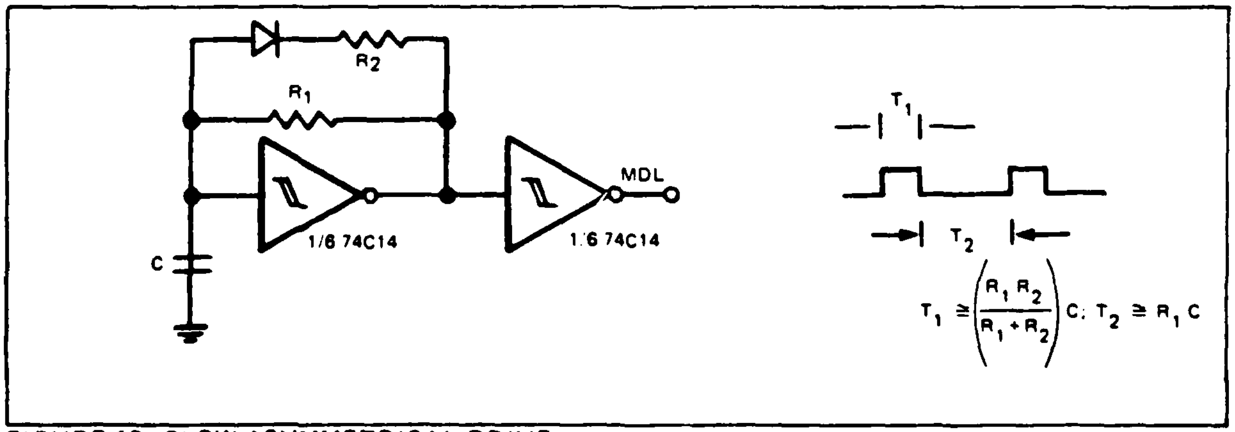


FIGURE 15. SLOW ASYMMETRICAL DRIVE

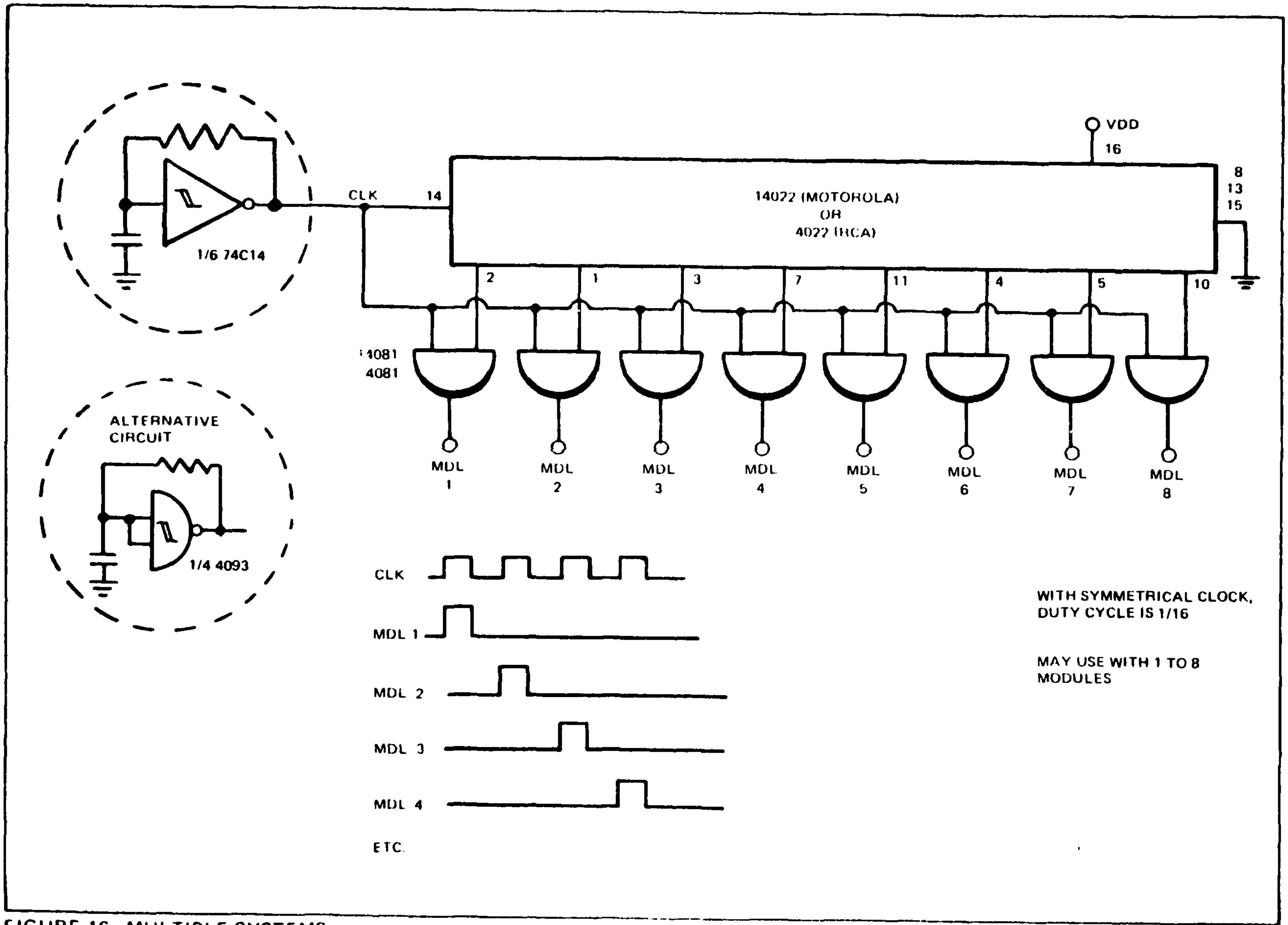
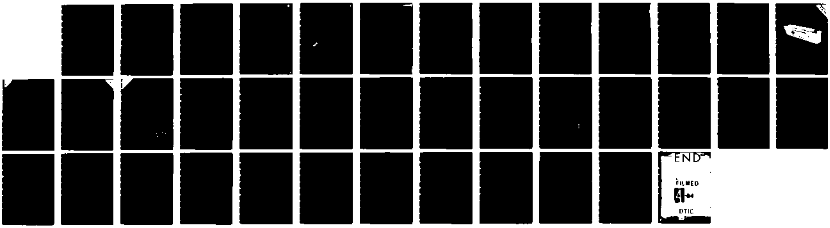
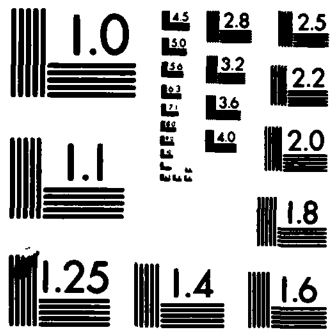


FIGURE 16. MULTIPLE SYSTEMS

AD-A138 348 ENVIRONMENTAL MAPPING BY A HERO-1 ROBOT USING SONAR AND A LASER BARCODE SCANNER(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. R J OWEN 2/2

UNCLASSIFIED DEC 83 AFIT/GE/EE/83D-52 F/G 6/4 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figure 17 is a fixed gain test circuit. It is a simple circuit that may be built from readily available parts. The circuit produces a single frequency transmit burst of 8, 16, 32 or 64 cycles and repeats at regular intervals of about 200 ms. It features adjustable blanking, a fixed gain amplifier, a detector and complementary, buffered, echo-detect outputs. The transmit frequency is adjustable by means of a potentiometer.

This circuit is intended as a starting point in arriving at a system design where the sophistication of the ultrasonic circuit board is not needed.

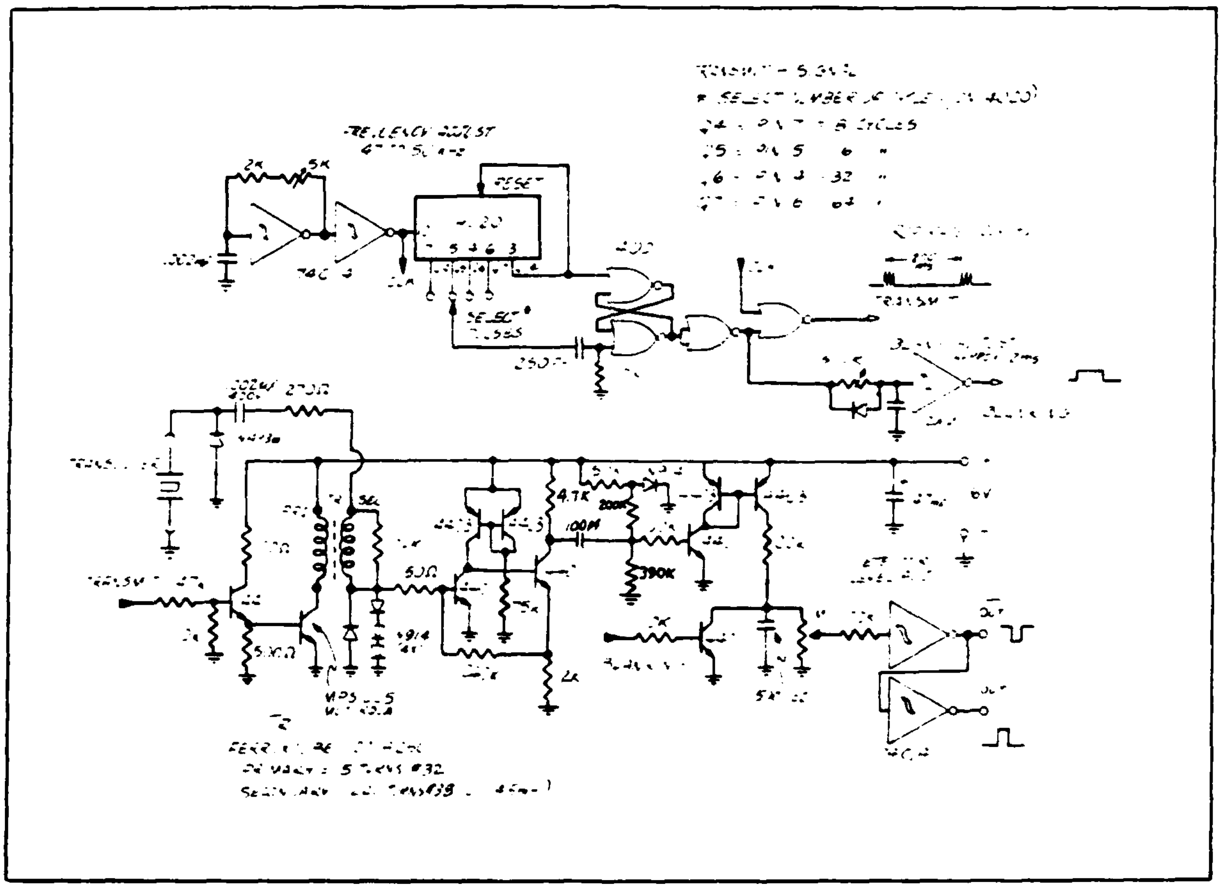


FIGURE 17. FIXED-GAIN TESTER CIRCUIT

III - EXPERIMENTAL DEMONSTRATION BOARD

A. GENERAL DESCRIPTION

The experimental demonstration board (EDB) enables ranging to be performed with the Polaroid Ultrasonic Ranging Unit. A digital readout displays measured distances five times each second in tenths-of-a-foot. It has a range of 0.9 feet to 35.0 feet.

WARNING: Be certain that the transducer is properly connected to the ultrasonic circuit board before applying power. Applying power to the board with the transducer disconnected may damage the board.

The EDB has all the necessary circuitry to interface with the Ultrasonic Ranging Unit (Figure 18).

The acoustical transducer is connected to the ultrasonic circuit board which, in turn, is connected to the EDB. The EDB provides the circuit board with a switching voltage, a constant plus voltage and a ground return. The circuit board provides the EDB directly with the transmit signal and the received echo signal.

A time-window, directly related to distance, is generated by the transmit signal and the received echo. A 420 kHz clock on the EDB allows accurate measuring of this time-window.

The switching voltage applied to the circuit board causes it to transmit and receive repeatedly, providing a new time-window each cycle. After each cycle, the EDB measures the time-window, converts the time-window into distance and displays the distance digitally until the next cycle updates the information.

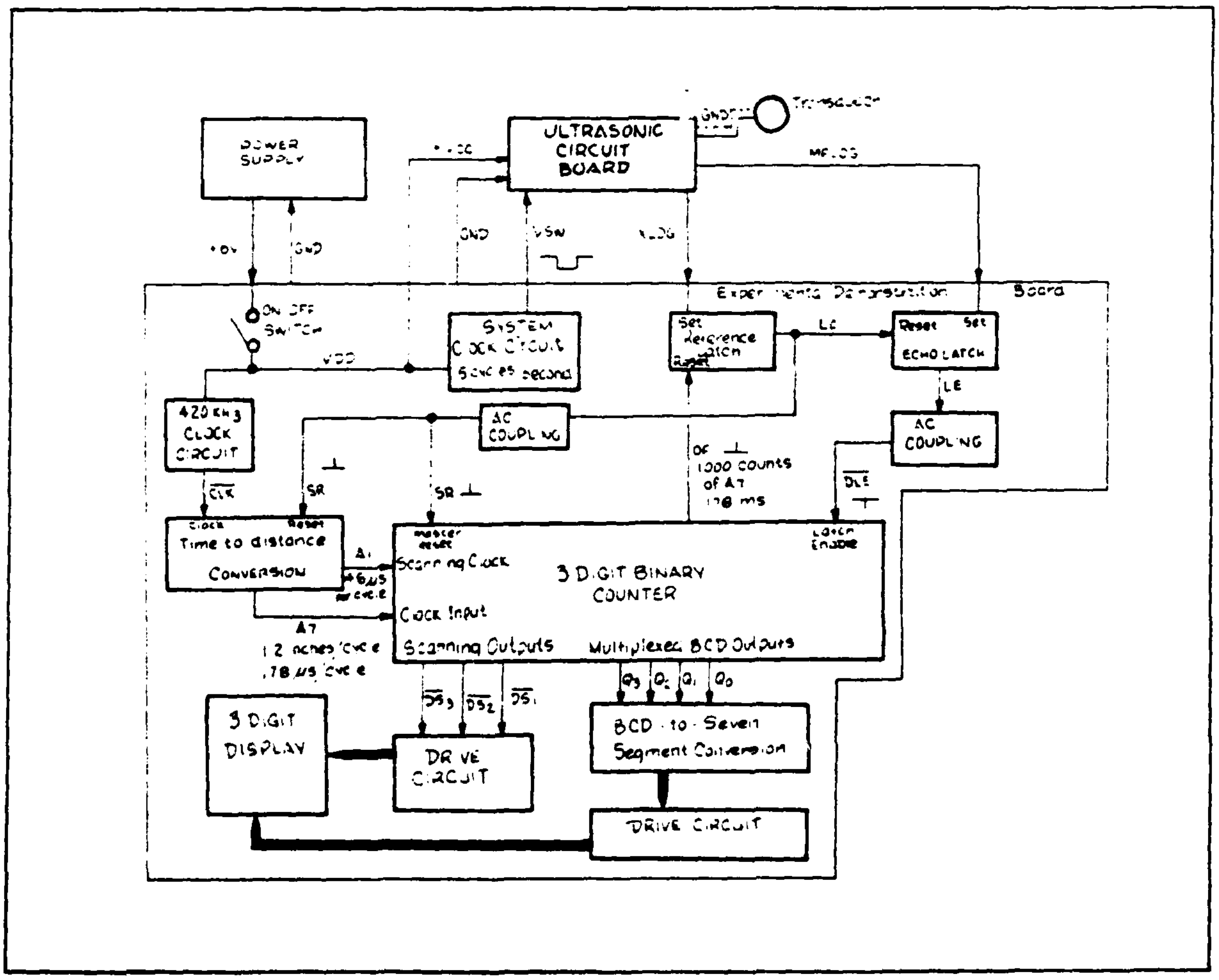


FIGURE 18. BLOCK DIAGRAM

B. SYSTEM INTERCONNECTIONS (Figure 19)

Connect the acoustical transducer to the ultrasonic circuit board. Connect the center conductor of the coaxial cable between the positive (+) transducer terminal and terminal 2 on the board. Connect the shield between the negative (−) transducer terminal and terminal 1 on the board.

A 6 volt, 2.5 ampere power supply must be connected to the EDB. The plus (+) 6 volt wire connects with terminal #[6] on the EDB. The ground from the power supply connects with terminal #[7].

The EDB provides switching voltage VSW. Connec terminal #[5] to terminal #9 on the circuit board.

NOTE: To switch the circuit board, pin #10 on the Interface Chip has been disconnected Figure 20 shows other alterations.

The EDB provides constant voltage +VCC and ground return GND. Connect terminal #[4] to terminal #8 and terminal #[3] to terminal #3 on the circuit board. Connect GND terminal #[8] to terminal #10 on the circuit board.

The Ultrasonic circuit board provides the EDB with the transmit signal and the received echo.

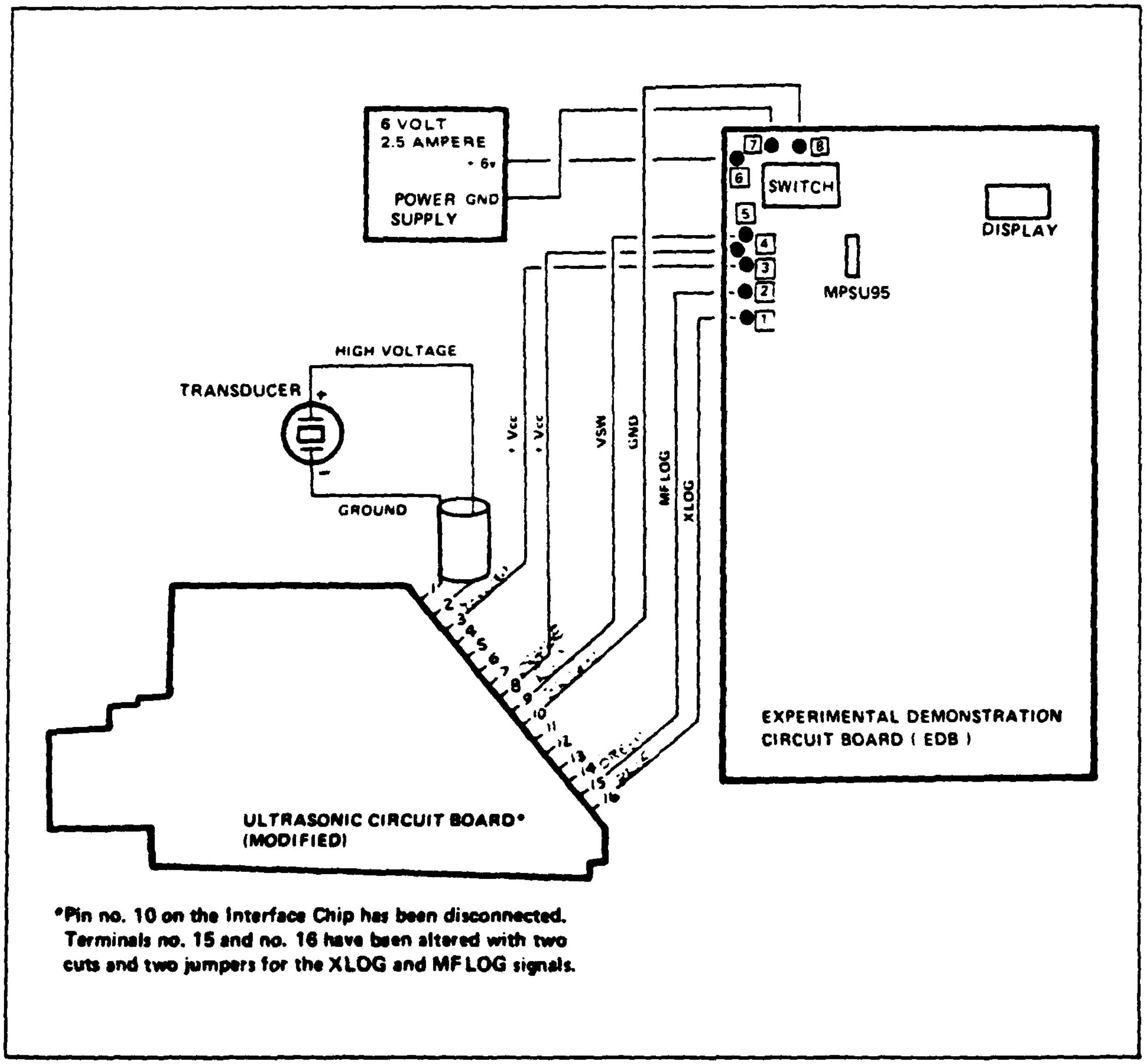


FIGURE 19. INTERCONNECTIONS (EDB) ULTRASONIC RANGING SYSTEM

Connect transmit signal XLOG, terminal #$\boxed{1}$ on the EDB, to terminal #16 on the circuit board. Connect received echo signal MFLOG, terminal #$\boxed{2}$ on the EDB, to terminal #15 on the circuit board.

There are six connections between the EDB and the circuit board. There are two connections from the EDB to the power supply. There are two connections between the transducer and the ultrasonic circuit board. These ten interconnections are required to demonstrate the Ultrasonic Ranging System.

A one-inch square of Polaroid circularly polarized filter (red) is included in this kit to increase the readability of the display. To correctly orient the filter, place it over a shiny silver coin such as a nickel or quarter. If the coin is visible through the filter, turn the filter over – the coin should now be much darker or not visible. The filter is correctly oriented for use with the display when the coin is either not, or barely, visible.

C. SUPPORTING DIAGRAMS

1. Figure 21, EDB Circuit Diagram.
2. Figure 22, Ultrasonic Ranging System Timing Diagram.
3. Figure 23, EDB Component Layout and Printed Circuit Board.

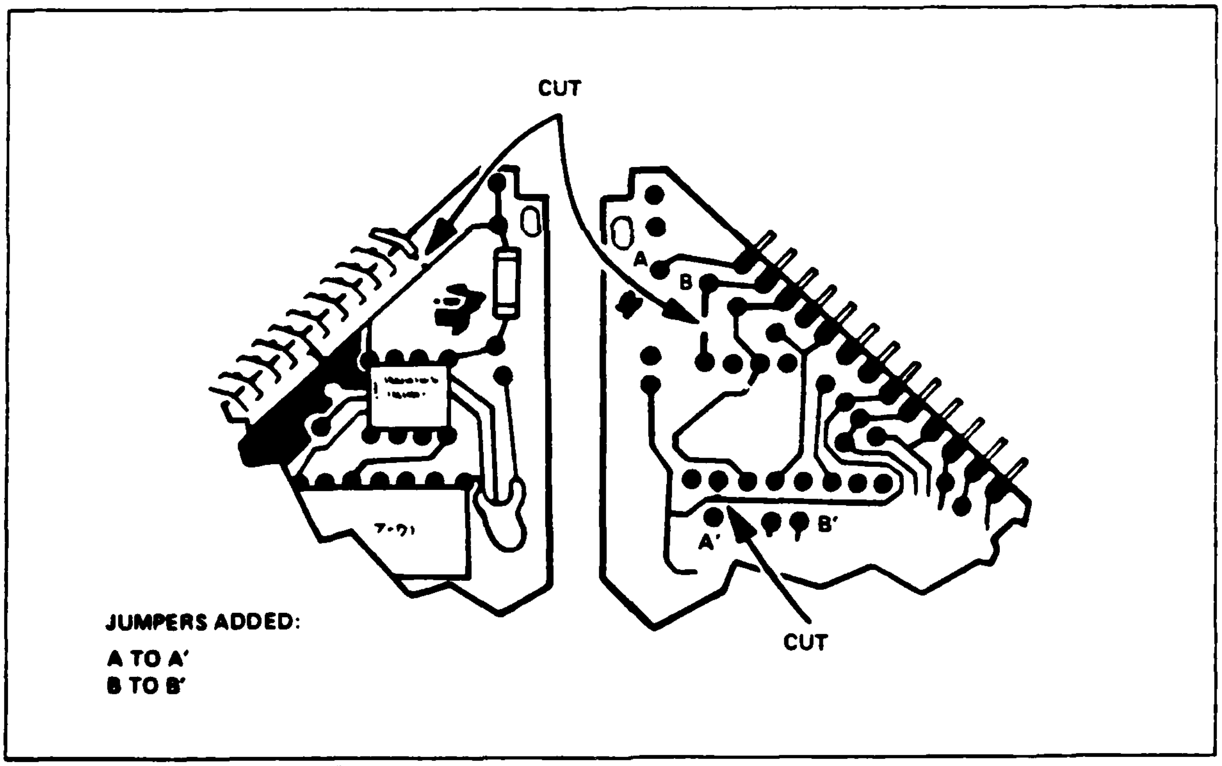


FIGURE 20. EXISTING ULTRASONIC CIRCUIT BOARD ALTERATIONS

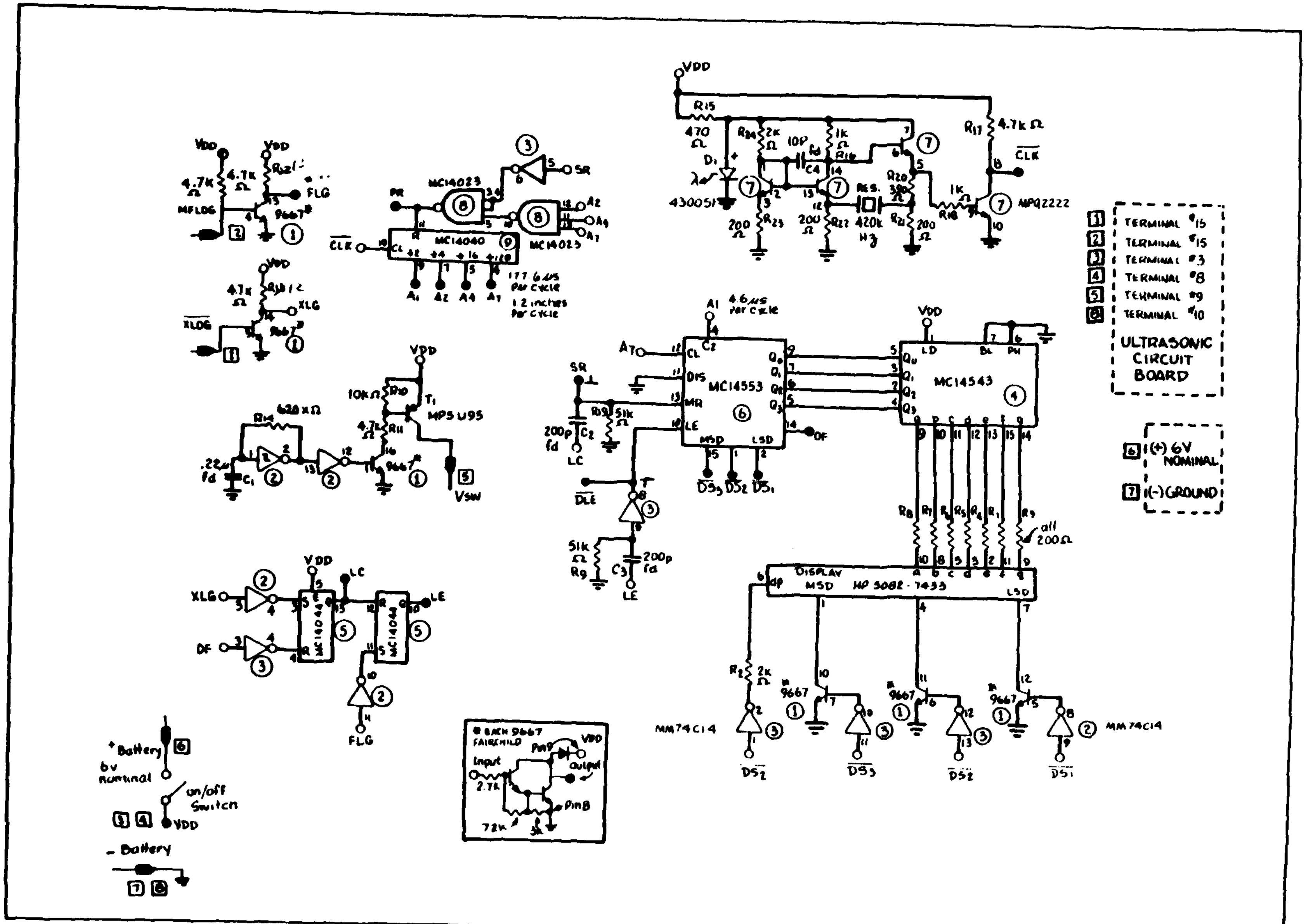
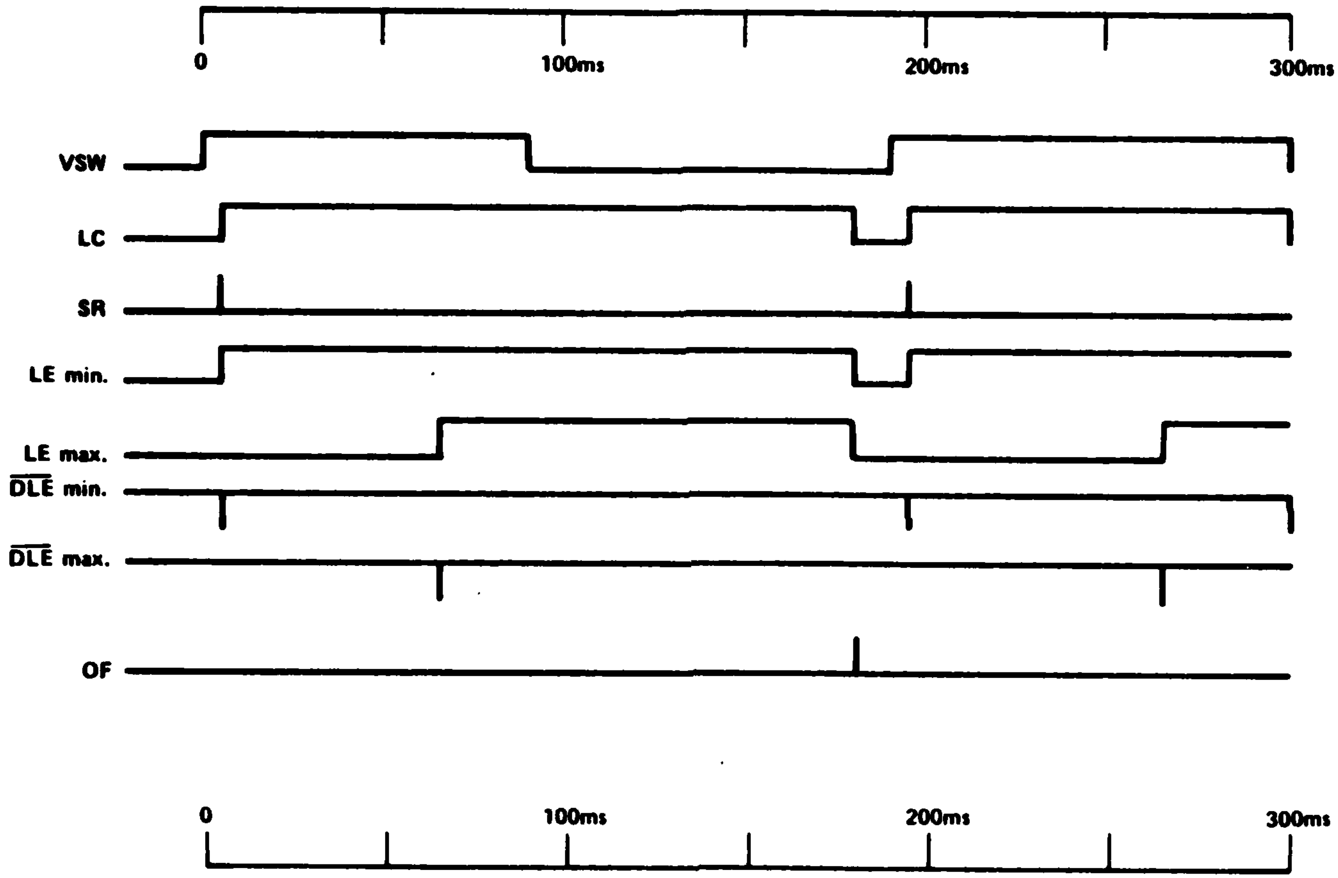


FIGURE 21. EDB CIRCUIT DIAGRAM



LC is the reference.
LE min. is the earliest echo received, .9 feet (1.6ms).
LE max. is the furthest echo received 35.0 feet (62.2ms).
OF is 177.6ms from LC.

FIGURE 22. TIMING DIAGRAM ULTRASONIC RANGING SYSTEM

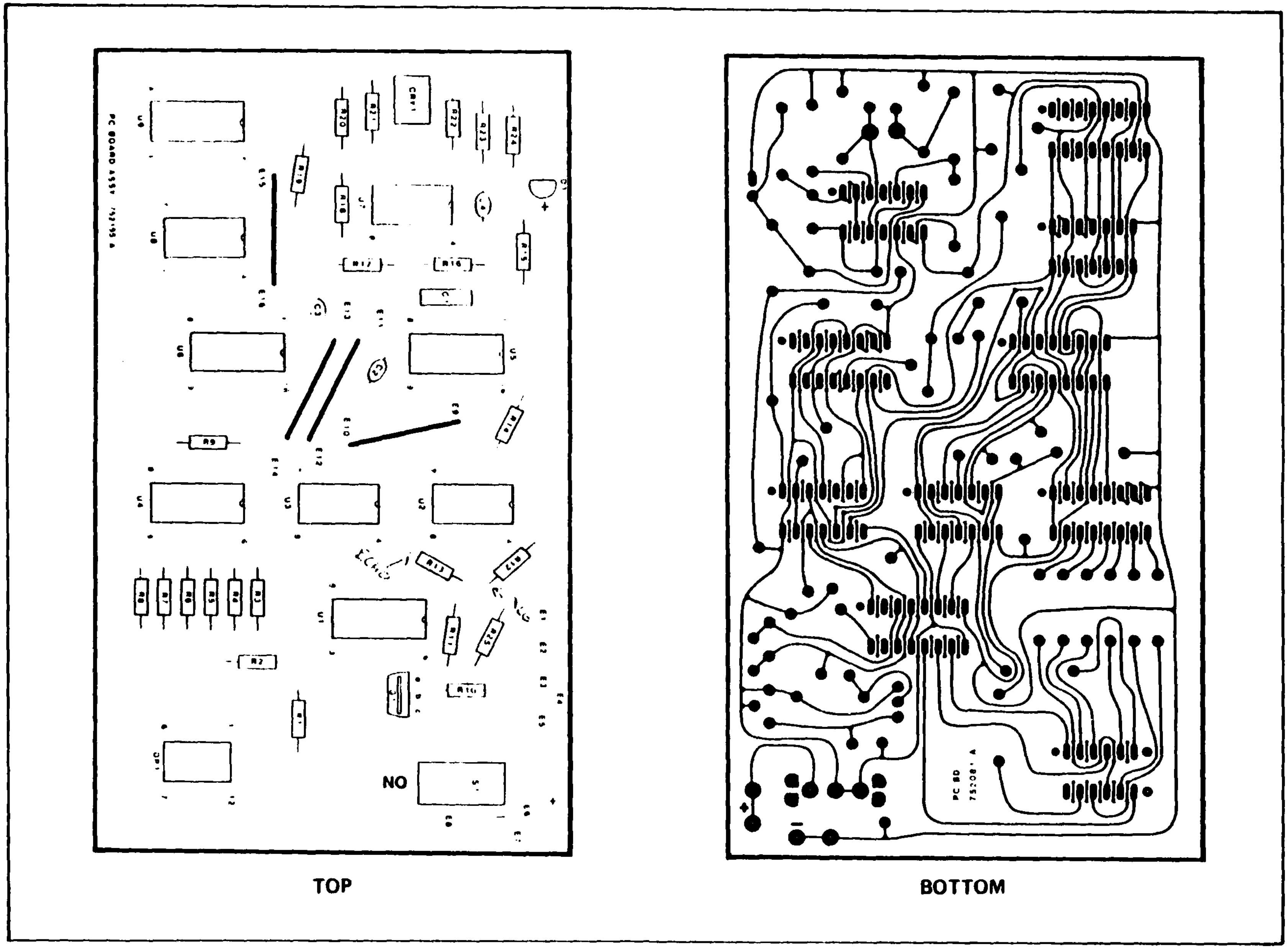


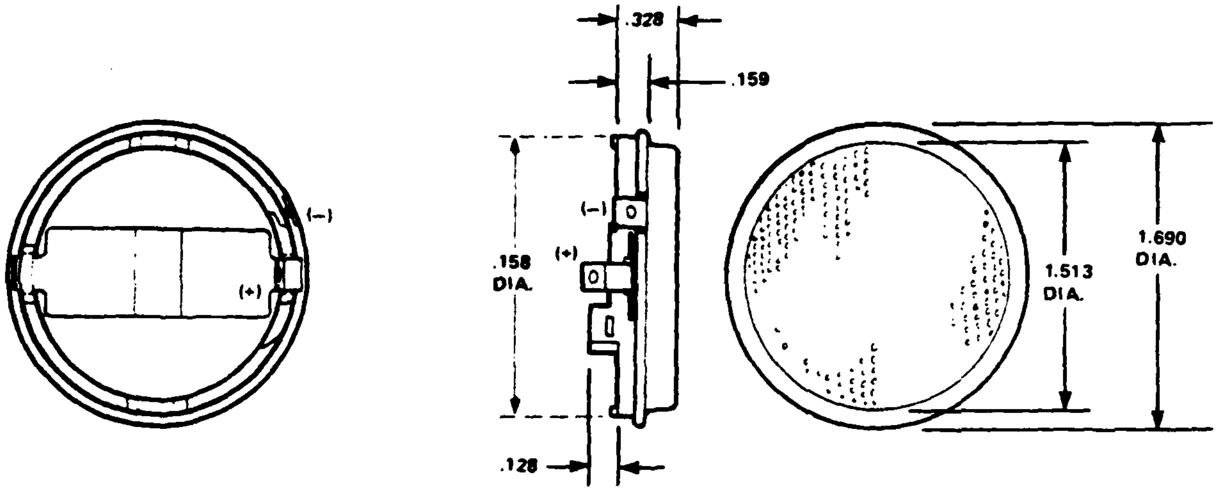
FIGURE 23. EDB COMPONENT LAYOUT AND PRINTED CIRCUIT BOARD.

IV - TECHNICAL SPECS

A. ELECTROSTATIC TRANSDUCER – INSTRUMENT GRADE

General Description

This electrostatic transducer is specifically intended for operation in air at ultrasonic frequencies. The assembly comes complete with a perforated protective cover and slip-on connectors.

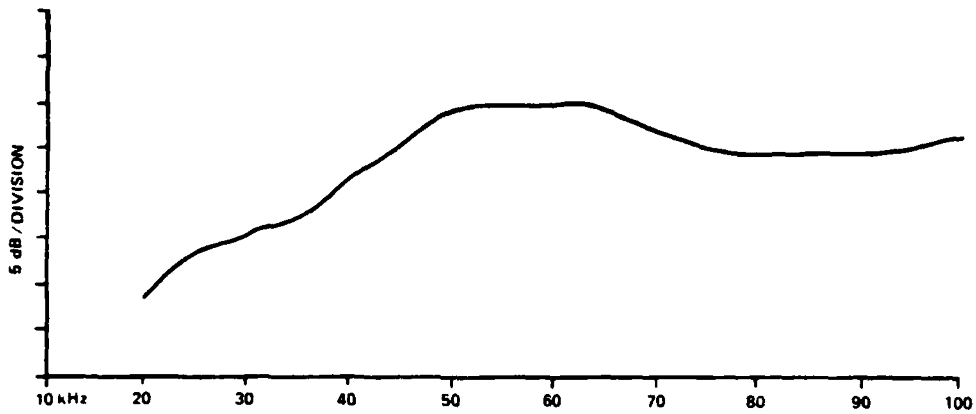


Specifications

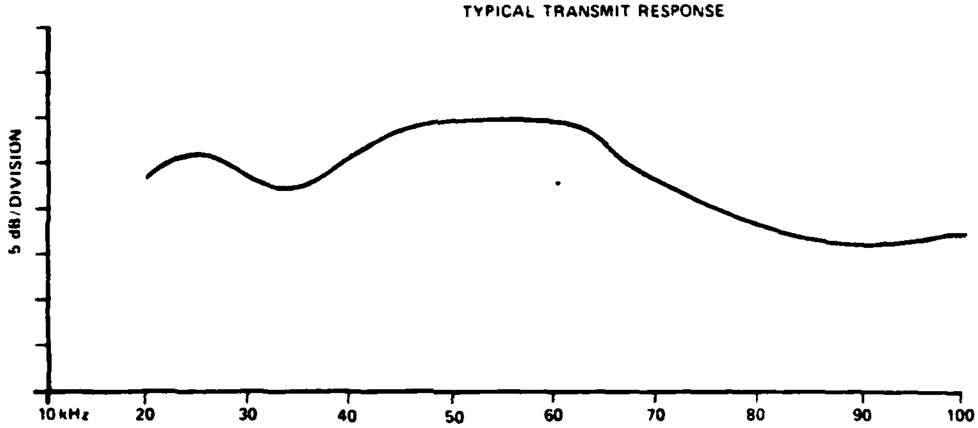
Usable Transmitting Frequency Range	See Graph
Usable Receiving Frequency Range	See Graph
Beam Pattern	See Graph
Minimum Transmitting Sensitivity at 50 kHz 300 vac pk-pk, 150 vdc bias (db re 20 uPa at 1 meter)	110 dB
Minimum Receiving Sensitivity at 50 kHz 150 vdc bias (dB re 1v/Pa)	– 42 dB
Suggested DC Bias Voltage	150 V
Suggested AC Driving Voltage (peak)	150 V
Maximum Combined Voltage	400 V
Capacitance at 1 kHz (Typical) 150 vdc bias	400 - 500 pf
Operating Conditions Temperature Relative Humidity	 32° - 140° F 5% - 95%
Standard Finish Foil Housing	 Gold Flat Black

Specifications subject to change without notice.

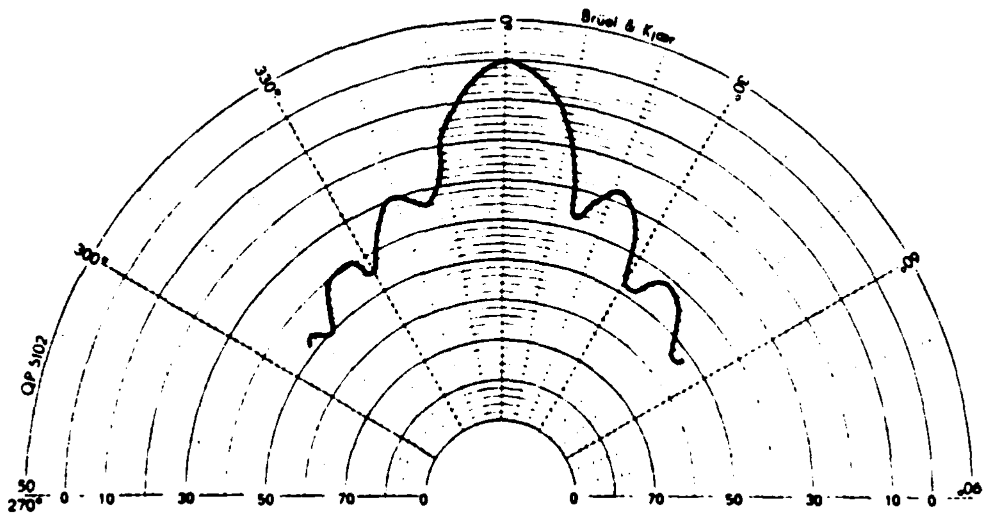
NOTE: These curves are representative only. Individual responses may differ.



TYPICAL TRANSMIT RESPONSE



TYPICAL FREE FIELD RECEIVE RESPONSE



TYPICAL BEAM PATTERN
AT 50 kHz

NOTE db normalized to on axis response.

Addendum to Polaroid Ultrasonic Ranging System Manual

1. One circuit change has been made since the technical manual was printed which affects some of the early production Experimental Demonstration Boards. These boards have already been modified to insure proper operation.

   In our camera systems we maintain one strict rule concerning our ultrasonic modules. From time of transmit to receive, we inhibit all other high current electronic or electro-mechanical camera activity. This insures as noise-free an environment as possible. This is important because in the later high gain steps, the Ultrasonic Circuit Board is very susceptible to noise. The user should be aware of this when interfacing the Ultrasonic Circuit Board with other electronics.

   The following modifications have been made to the Experimental Demonstration Board:

   1. Isolate pin 7 of U4.
   2. Reconnect pin 6 of U4 to ground.
   3. Connect pin 10 of U5 to pin 5 of U2.
   4. Connect pin 6 of U2 to pin 7 of U4.

   These changes provide a signal to the display driver which blanks the display from the beginning of each cycle until MFLOG goes low signalling echo received.

2. We will now be offering the Ultrasonic Circuit Board for sale as well as the Ultrasonic transducers. (Limited quantitity available)

ERRATA

1. The labels R12 and R13 should be switched on Figures 21 and 22 as well as on the silkscreen of the Experimental Demonstration Board.

Appendix E: Barcode Scanner Data Sheet

InstaRead Seri
Bar Code Readers

InstaRead I

MOVING-BEAM LASER SCANNER

InstaRead Series industrial bar code readers are specifically designed for use in rugged factory environments. A decade of bar code reading experience has been incorporated into the most flexible, most compact and most advanced laser reading system on the market.

INSTAREAD
CORPORATION

Industrial Systems for Management and Control

InstaRead

General Description of InstaRead I

InstaRead I is a moving-beam laser scanner designed for bar code reading. This single package unit – measuring only 4¾" x 5¼" x 21" – contains the complete working system – laser, scanner, decoder and processor. The rugged aluminum Nema 12 designed outer shell is furnished with a protective end-housing for the beam exit window. This modular housing can be simply interchanged with optional configurations for 90° side scanning, 2° to 15° raster (x-y) scan field or a protective shutter for the window which can be remotely controlled. While the shutter is closed, no foreign materials can reach the beam exit window, reducing preventative maintenance frequency.

Inside the outer shell is the operating module which contains the complete operating system and can be removed in just seconds without disturbing the alignment or position of the scanner. The module incorporates advanced state-of-the-art designs and micorcircuitry that allows the user to select from a full menu of operating standards – such as baud rates, parity, word format, handshake and the like – with easy single-button entry from the InstaRead remote hand held programmer. This low-cost optional programmer features a 16-character display. The InstaRead I can be programmed via nonvolatile memory to operate as many as eight different code types and character lengths, up to 40 on each code channel.

That's right! The system will read up to eight code symbologies indiscriminately and any two in the same sweep sequence.

SAMPLE SELECTION

Code Type	Number of Characters				
1. 39	3-digit	7-digit	12-digit	13-digit.	etc.
2. 2 of 5	4-digit	5-digit	20-digit	36-digit.	etc.
3. I-2 of 5	10-digit	12-digit	18-digit	40-digit.	etc.
4. AS-10	6-digit	7-digit	13-digit	21-digit.	etc.
5. Other Code	–	–	–	–	
6. Other Code	–	–	–	–	
7. Other Code	–	–	–	–	
8. Other Code	–	–	–	–	

The system is programmed to read any of the preselected symbols shown in the table above, for example, as the beam sweeps code 39 (12-digits) and Code 2 of 5 (20-digits), the system will process each of the two decoded symbols.

The system is configured at the factory for specified selections and is ready to use upon installation. Subsequently, the user can edit and change or delete selections by using the optional programmer or any standard CRT terminal. The InstaRead remote programmer displays easy-to-follow instructions for entering or editing a selection or for performing diagnostic tests.

Impressed? Well, there's lots more.

InstaRead Corporation warranties its products (systems and laser tubes) for a period of one year. Each system has "laser level detection" that is preset to indicate that the laser output has decreased below an acceptable level. Should this level occur, an amber indicator on the unit will light. Also an external light or relay can be set providing a remote failure indication.

In the event a system indicates servicing, the units have a full range of troubleshooting and diagnostic aids for in-plant repair.

Standard Features

- 3-D Real-Time Decoding
  Dynamic-Differential-Decoding (3-D) using a new advanced real-time decoder with multisymbol read capability.

- High-Speed Scanning
  Bidirectional scan sweep (750 scans per second).

- Selectable Symbol/Code Length
  Select up to 40 preset code lengths for each of the eight possible symbol selections (320 combinations) of symbol and code length.
  Available on an off-the-shelf basis.

- Real-Time Diagnostics
  On-board indicators display system performance while the real-time diagnostics evaluate the laser power and read quality.

- "Intelligent" Programmable Processor
  Easy-to-use system programming with displayed prompting stores system configuration instructions into the nonvolatile memory. The processor can be pre-programmed at the factory or controlled on-line with the user's CRT terminal or optional remote hand held programmer.

- Industrial NEMA 12 Aluminum Enclosure
  Industrial enclosure allows attachment of modular low-cost options for raster pattern, automatic protective shutter and 90° side scanning.

- Industrial Nema-rated metal mating connectors included.

- One-Year warranty on the System and Tube.

- OEM and quality discounts.

Optional Features

- Raster (Adjustable 2°-15° Pattern)
- Automatic Shutter
- 90° End Housing
- Remote hand held programmer with 16-character alphanumeric display and keyboard.
- Remote power/interface module.
- Control Relays (AC or DC).
- Part-present detector.
- InstaData intelligent external processor.*
- Universal swivel mounting hub.

* *Consult factory*

InstaRead

SPECIFICATIONS

ENCLOSURE
Type: Aluminum
Design: NEMA 12
Size: 4¾" x 5¼" x 21"
Mounting: Fixed or swivel
Weight: 14 lbs.
Finish: Blue enamel

POWER REQUIREMENT
(without remote power supply)
+13 to +16 VDC, unregulated;
2.8 A, maximum*
(with remote power supply)
120/240 VAC ± 10%; 1 A, maximum

*Some options require slightly more. Consult Factory.

OPERATING ENVIRONMENT
Standard: 32° to 110°F
Relative humidity 95%, noncondensing

DISPLAY INDICATORS
Green: Blinks on "Good Read"
Red: Laser Power "ON"
Amber: Steady – "Low Laser Power"

CODE LENGTH
1 to 40 characters for each Code Type

STANDARD CODE TYPES AVAILABLE
Code 39 / 2 of 5 Code
Interleaved 2 of 5 Code
Codabar / AS-10 Code
Bidirectional 2 of 5 Code
Plus special custom codes.*

*Consult Factory.

InstaRead has a policy of continuous product research and improvement and reserves the right to change design and specifications without notice.

LASER
Type: HeNe
Power: 2 milliwatts
Class: BRH II
Warranty Period: One Year

SCANNER
Type: Bidirectional
Angle: 30° (nominal)
Scan Speed: 750 scans per second

READ PARAMETERS*

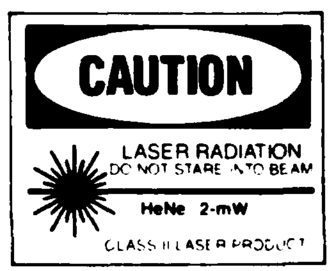
Read Range	2" to 36"
Skew/Yaw	to 60°
Pitch/Roll	to 60°
Scan Height	16" at 24" distance, typical
Depth of Field	36" (0.030" minimum bar)

*Dependent on label size and quality.

COMMUNICATIONS
Full Duplex: (standard)
Baud Rate: 300 to 9,600 (selectable)
Parity: Odd/Even/Mark/Space (selectable)
Handshake: CTS-RTS or ACK-NAK (selectable) plus programmable post and pr ambles for control character string
Word Format: 1 Start/8 Data/1 Stop Bits
I/O: Serial RS-232 or 20 mA passive current loo
(For optional I/O see Remote Power Supply.)

• The low energy laser supplied in this equipment is not harmful to th skin. As with 100-watt incandescent lamps, ARC lamps or the su careless, prolonged eye exposure should be avoided.

*Consult factory.



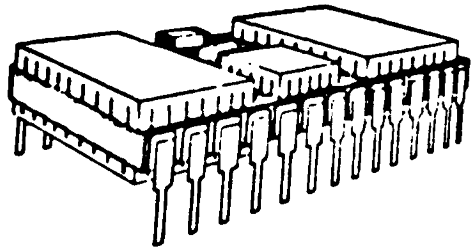
INSTAREAD
CORPORATION
2400 DIVERSIFIED WAY • ORLANDO, FLORIDA 32804
305 843-8975 • TELEX 564407 • WATS 800 843-2700

August 1983
Printed in USA
PUB INSRDI-2

Appendix F: EDH8808 8k x 8 RAM Data Sheet

ELECTRONIC DESIGNS INC

EDH8808
8,192 x 8 BIT STATIC RANDOM ACCESS MEMORY



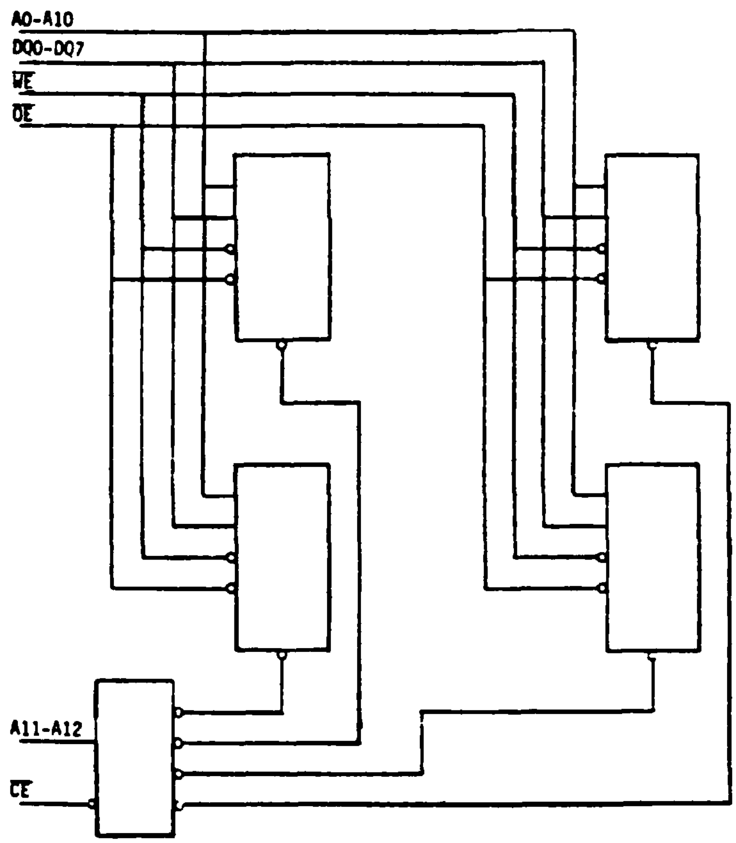
FEATURES

- 8,192 x 8 bit RAM
- Completely static operation
- Standard 28 pin JEDEC pinout
- 400 mW maximum
- Directly TTL compatible
- Three state output
- Single +5 volt supply operation
- Pin compatible with standard 64K EPROMS/ROMS

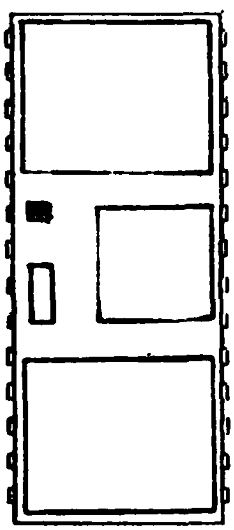
DESCRIPTION

The EDH8808 is a high density module utilizing four 2K x 8 static RAMs and a decoder in leadless chip carriers. The EDH8808 is intended for use in any application where large quantities of static memory are required and/or board space is of prime concern. The EDH8808 is pin compatible with the 2764 EPROM and can be used for firmware development. Sample applications include terminals and single board computers.

FUNCTIONAL DIAGRAM



PINOUTS



NC	1	28	VCC
A12	2	27	WE
A7	3	26	NC
A6	4	25	A8
A5	5	24	A9
A4	6	23	A11
A3	7	22	OE
A2	8	21	A10
A1	9	20	CE
A0	10	19	DQ7
DQ0	11	18	DQ6
DQ1	12	17	DQ5
DQ2	13	16	DQ4
VSS	14	15	DQ3

PIN NAMES

A0-A12	Address Inputs	VCC	Power (+5 Volts)
CE	Chip Enable	WE	Write Enable
VSS	Ground	OE	Output Enable
DQ0-DQ7	Data In/Out		

ABSOLUTE MAXIMUM RATINGS* (see note 1)

Voltage on any pin relative to V_{SS} .... -0.5V to +7.0V
Operating Temperature .... $0^{o}C$ to $+70^{o}C$
Storage Temperature .... $-55^{o}C$ to $+125^{o}C$
Power Dissipation .... 2 Watts

*Stress greater than those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions greater than those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect reliability.

RECOMMENDED DC OPERATING CONDITIONS OVER OPERATING TEMPERATURE RANGE

PARAMETER	SYMBOL	MIN	TYP	MAX	UNITS
Supply Voltage	V_{CC}	4.5	5.0	5.5	V
	V_{SS}	0	0	0	V
Logical "1" Input	V_{IH}	2.2		V_{CC} +0.3	V
Logical "0" Input	V_{IL}	-0.3		0.8	V

DC ELECTRICAL CHARACTERISTICS OVER ALL RECOMMENDED OPERATING CONDITIONS (see note 2)

PARAMETER	SYMBOL	MIN	MAX	UNITS
Average Supply Current	I_{CC}		80	mA
Standby Supply Current	I_{SB}		20	mA
Input Leakage Current	I_L	-4.0	4.0	uA
Output Leakage Current	I_{OL}	-4.0	4.0	uA
Logical "1" Output Voltage	V_{OH}	2.4		V
Logical "0" Output Voltage	V_{OL}		0.4	V

CAPACITANCE (see note 3)

PARAMETER	SYMBOL	MAX	UNITS
Capacitance on A0-A10, $\overline{OE}$, $\overline{WE}$	C_{IN1}	31	pF
Capacitance on A11, A12, $\overline{CE}$	C_{IN2}	20	pF
Capacitance on D/Q pins	$C_{D/Q}$	55	pF

NOTES

1. All voltage referenced to Vss
2. Icc is dependent on cycle rates and output loading
3. High capacitance is due to four (4) parallel loads. This must be taken into consideration during system design

OPERATION

The EDH8808 is in the read mode whenever the Write Enable input ($\overline{WE}$) is in the high state. In the read mode of operation, the EDH8808 provides a fast address ripple-through access of data from 8 of 65,536 locations in the static storage array. Thus, the unique address specified by the 11 standard Address inputs and the two decoded address inputs define which 1 of 8,192 bytes of data is to be accessed.

Any transition on the 13 address inputs will disable the 8 Data Output Drivers. Valid Data will be available to the 8 Data Output Drivers after the last address input signal is stable, providing that the $\overline{CE}$ and $\overline{OE}$ access times are satisfied. If $\overline{CE}$ or $\overline{OE}$ access times are not met, data access will be measured from the limiting parameter ($\overline{CE}$ or $\overline{OE}$) rather than the address. The state of the 8 data I/O signals is controlled by the Chip Enable ($\overline{CE}$) and Output Enable ($\overline{OE}$) signals.

The EDH8808 is in the write mode whenever the Write Enable ($\overline{WE}$) and Chip Enable ($\overline{CE}$) inputs are in the low state. The write cycle is initiated by the WE pulse going low provided that $\overline{CE}$ is low. The leading edge of the $\overline{WE}$ pulse is used to latch the status of the address bus.

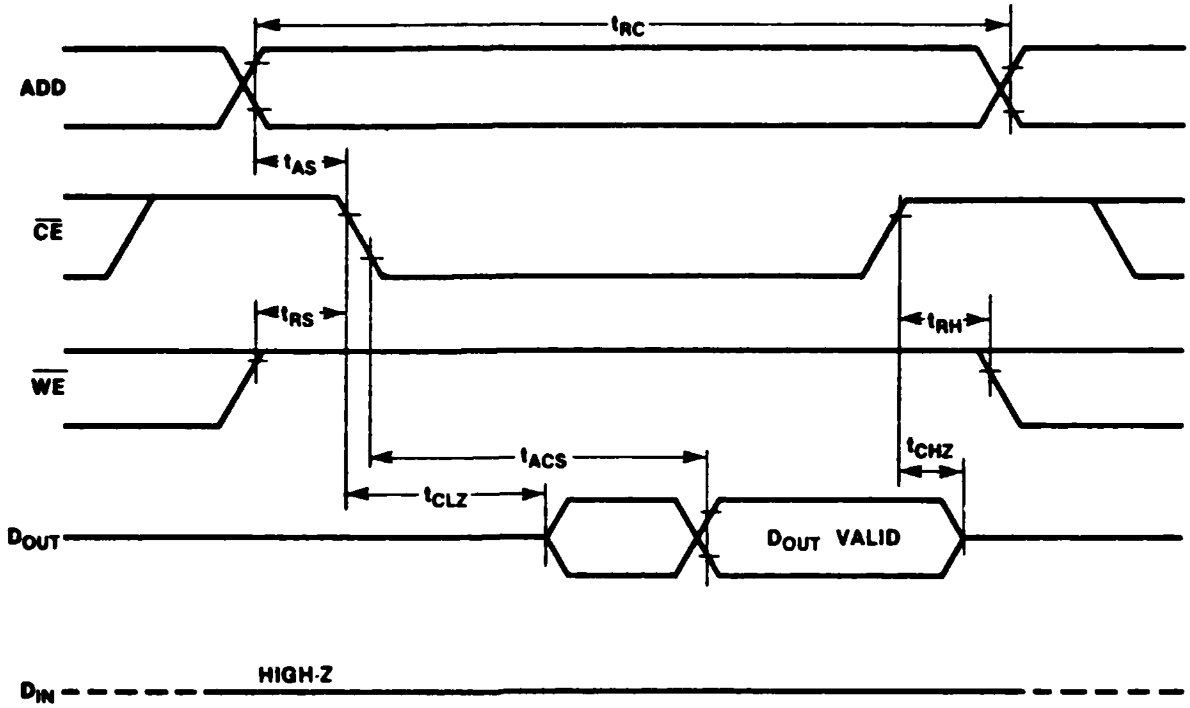
In a write cycle the latter occurring edge of either $\overline{WE}$ or $\overline{CE}$ will determine the start of the write cycle. Therefore, address set up time, write pulse duration and address hold time are referenced to the latter occurring edge of $\overline{CE}$ or $\overline{WE}$. Addresses are latched at this time. All write cycles whether initiated by $\overline{CE}$ or $\overline{WE}$ must be terminated by the rising edge of $\overline{WE}$. If the output bus has been enabled ($\overline{CE}$ and $\overline{OE}$ low) the $\overline{WE}$ will cause the output to go to the high Z state.

Data IN must be valid prior to the low to high transition of $\overline{WE}$. The Date IN must remain stable for data from write hold time after $\overline{WE}$ goes inactive. The write control of the EDH8808 disables the Data OUT buffers during the write cycle; however, $\overline{OE}$ should be used to disable the Data OUT buffers to prevent bus contention between the input data and data that would be output upon completion of the write cycle.

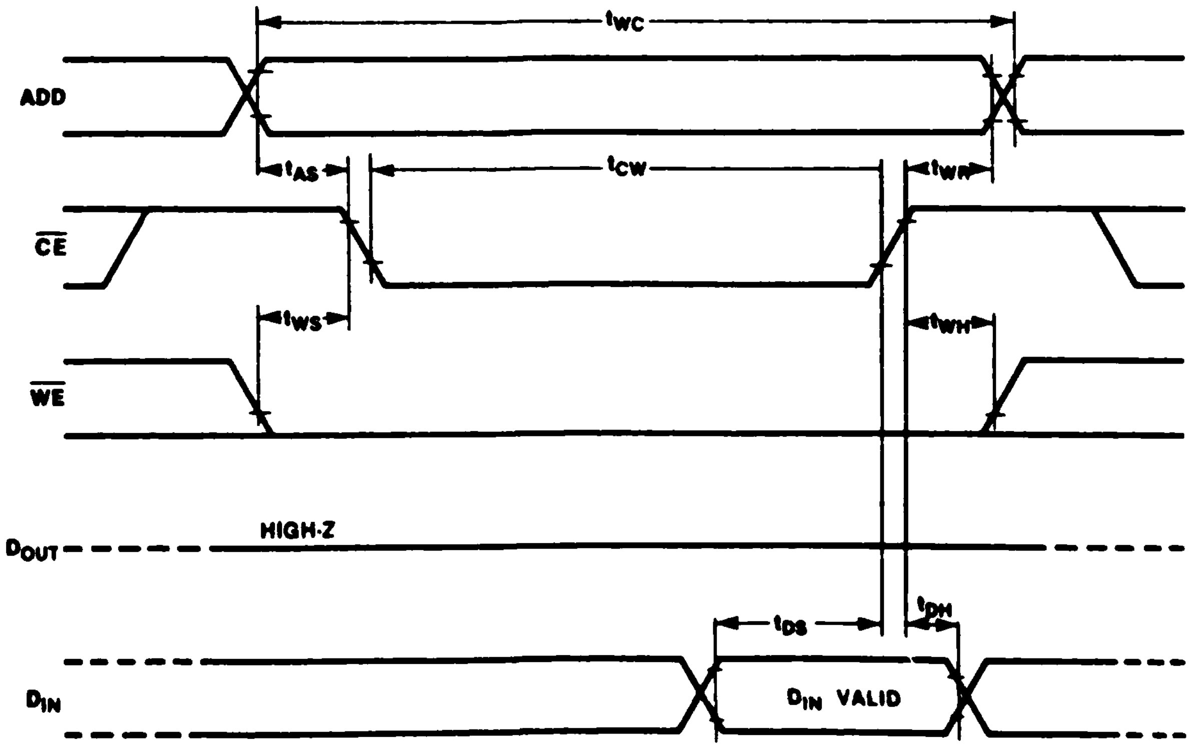
DYNAMIC CHARACTERISTICS OVER ALL RECOMMENDED OPERATING CONDITIONS

PARAMETER	SYMBOL	MIN	MAX	UNIT
Read Cycle Time	t_{RC}	210	---	nS
Write Cycle Time	t_{WC}	210	---	nS
Address Access Time	t_{AA}	---	210	nS
Chip Select Access Time	t_{ACS}	---	210	nS
Output Hold from Address Change	t_{OH}	25	---	nS
Output Low Z from $\overline{CE}$	t_{CLZ}	25	---	nS
Output High Z from $\overline{CE}$	t_{CHZ}	10	70	nS
Output Low Z from $\overline{OE}$	t_{OLZ}	15	---	nS
Output High Z from $\overline{OE}$	t_{OHZ}	---	60	nS
Output Enable to Output Valid	t_{OE}	---	100	nS
Output Active from End of $\overline{WE}$	t_{WLZ}	15	---	nS
Output High Z from $\overline{WE}$	t_{WHZ}	---	60	nS
Address Set-up Time	t_{AS}	10	---	nS
Address Valid to End of Write	t_{AW}	170	---	nS
Chip Selection to End of Write	t_{CW}	170	---	nS
Write Pulse Width	t_{WP}	140	---	nS
Write Recovery Time	t_{WR}	10	---	nS
Data Set-Up Time	t_{DS}	60	---	nS
Data Hold Time	t_{DH}	10	---	nS

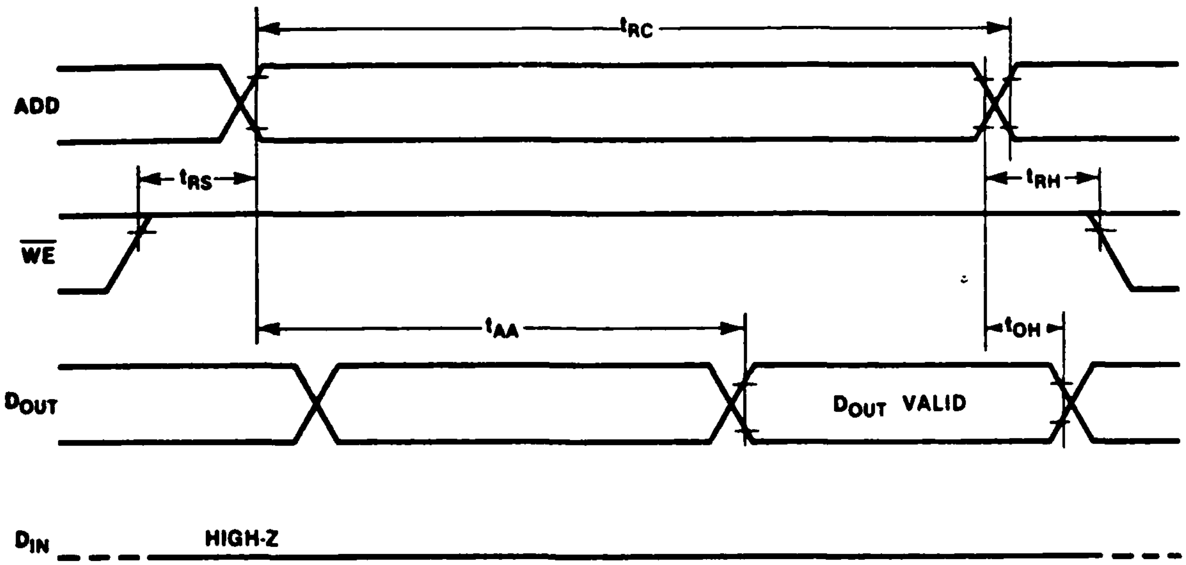
READ CYCLE ($\overline{CE}$ CONTROLLED, $\overline{OE}$ LOW)



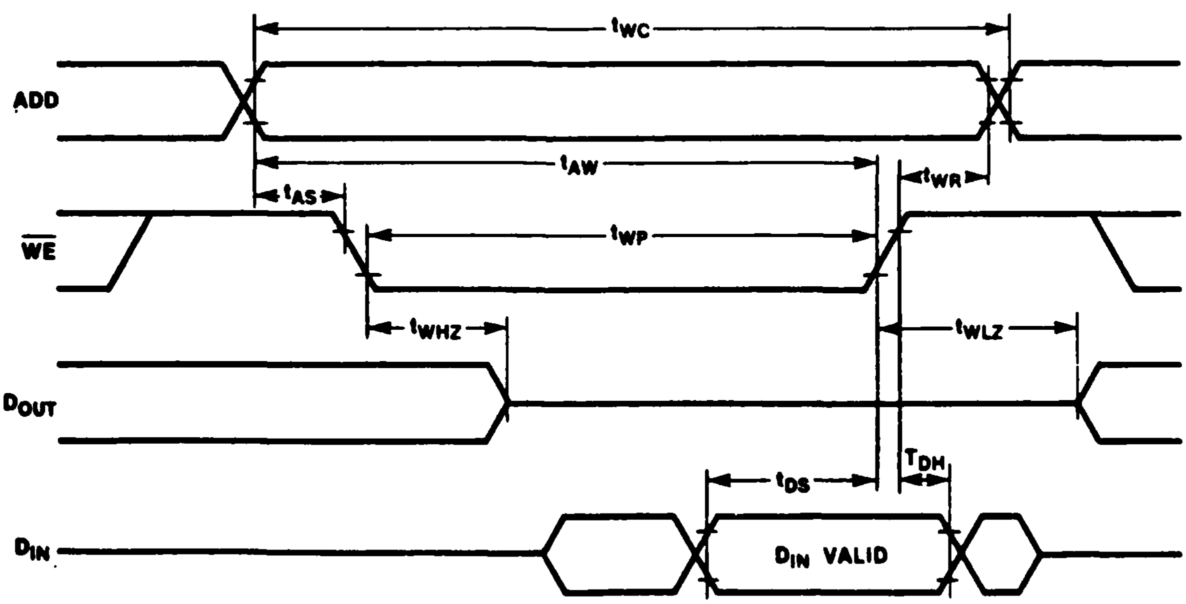
WRITE CYCLE ($\overline{CE}$ CONTROLLED, $\overline{OE}$ LOW)



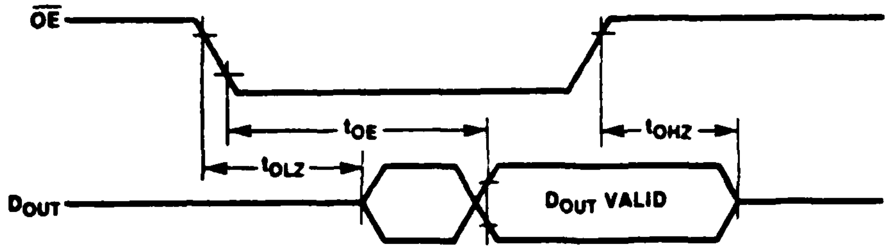
READ CYCLE ($\overline{WE}$ CONTROLLED, $\overline{CE}$ LOW, $\overline{OE}$ LOW)



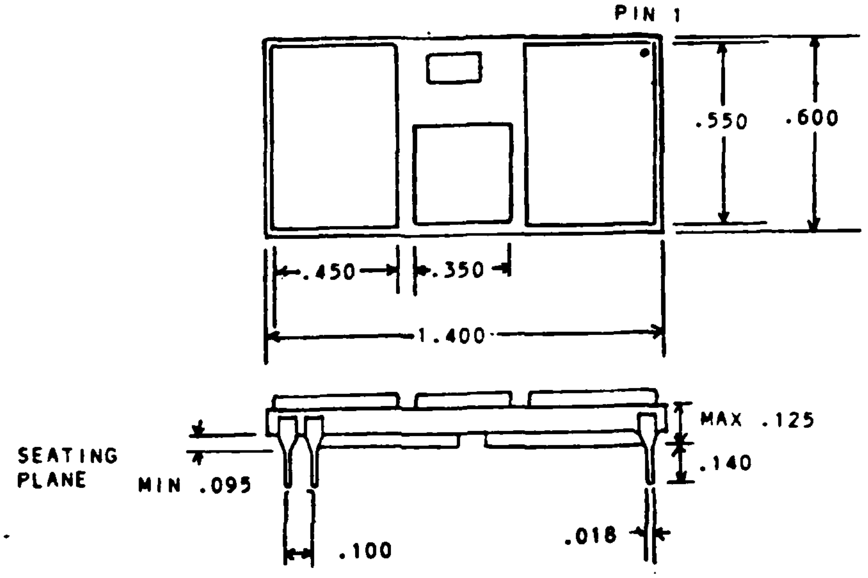
WRITE CYCLE ($\overline{WE}$ CONTROLLED, $\overline{CE}$ LOW, $\overline{OE}$ LOW)



OUTPUT CONTROL (OE CONTROLLED, CE LOW, WE HIGH)



DIMENSIONS



ORDERING INFORMATION

8808 X -SS -P T ZZZ

SCREENING LEVEL
BLANK = COMMERICAL
MR = EDI HI-REL
883B = 883B
883C = 883C
883S = 883S

TEMPERATURE (°C)
C = 0 - +70
I = -25 - +85
J = -55 - +85
M = -55 - +125

PACKAGE MATERIAL
P = PLASTIC
C = CERAMIC

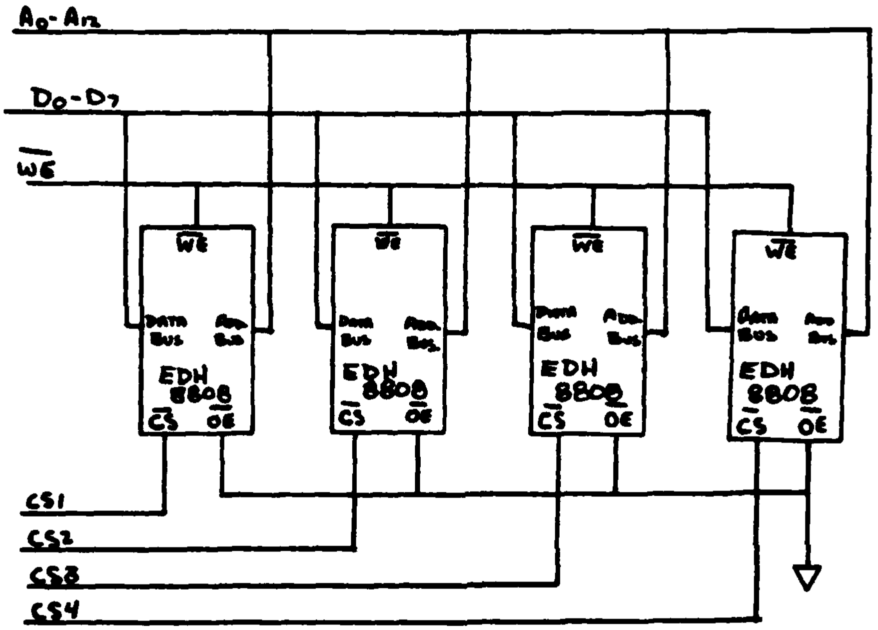
SPEED
200 = 210NS
150 = 150NS
120 = 120NS

TECHNOLOGY
BLANK = NMOS
C = CMOS

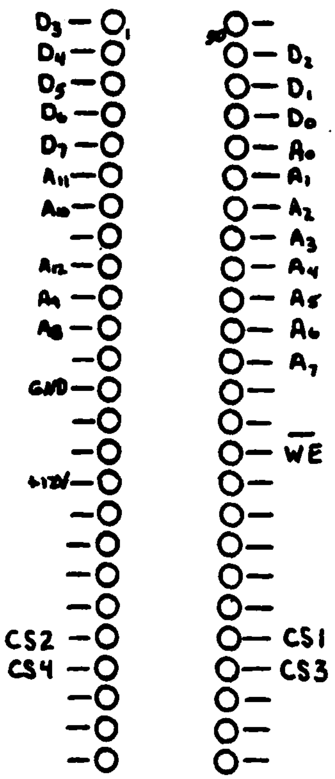
PART NUMBER FOR 8K X 8 STATIC RAM

ELECTRONIC DESIGNS INC
230 ELIOT STREET
ASHLAND, MASSACHUSETTS 01721
(617) 881-5244

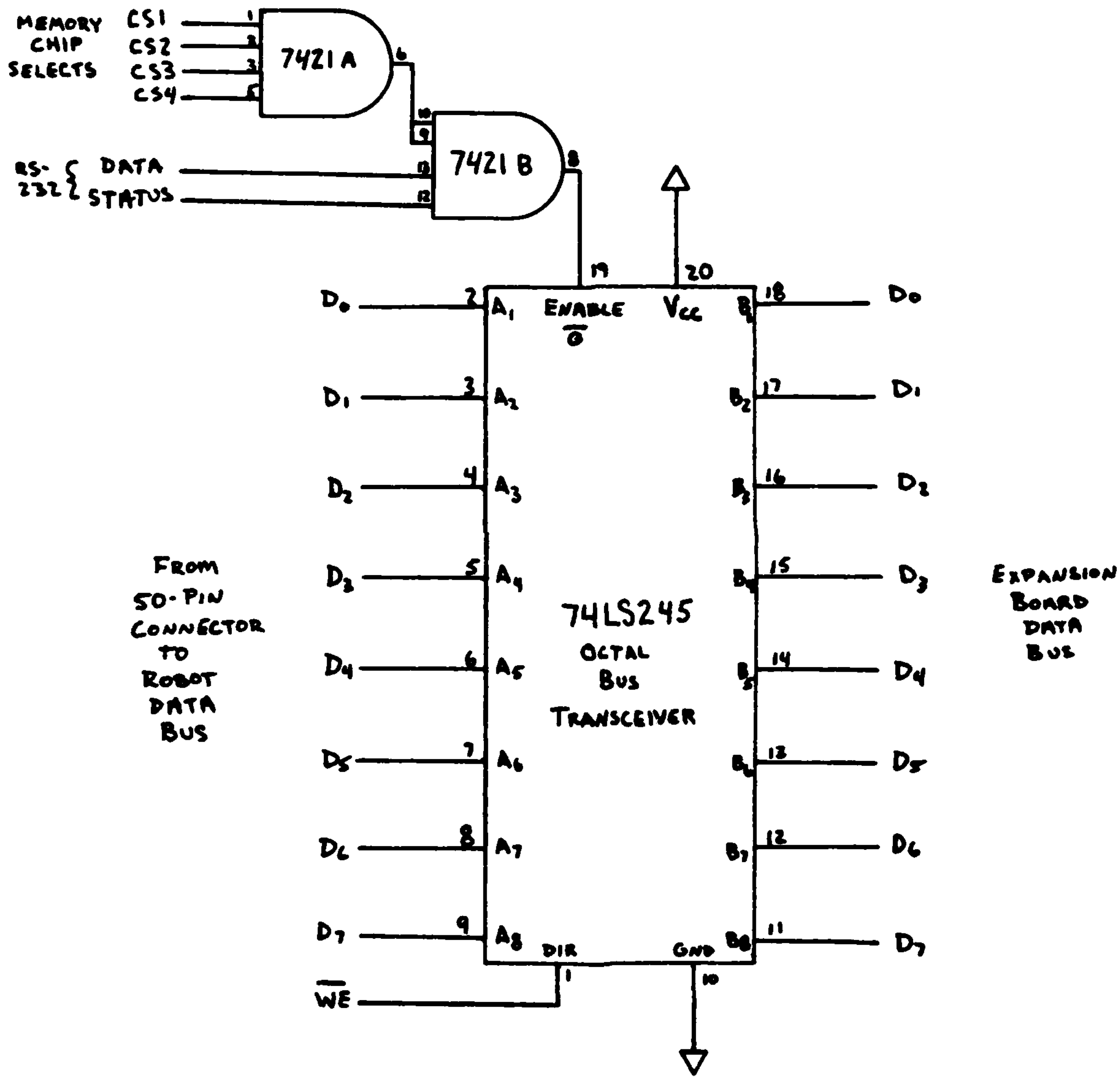
Appendix G: Added Circuit Schematics



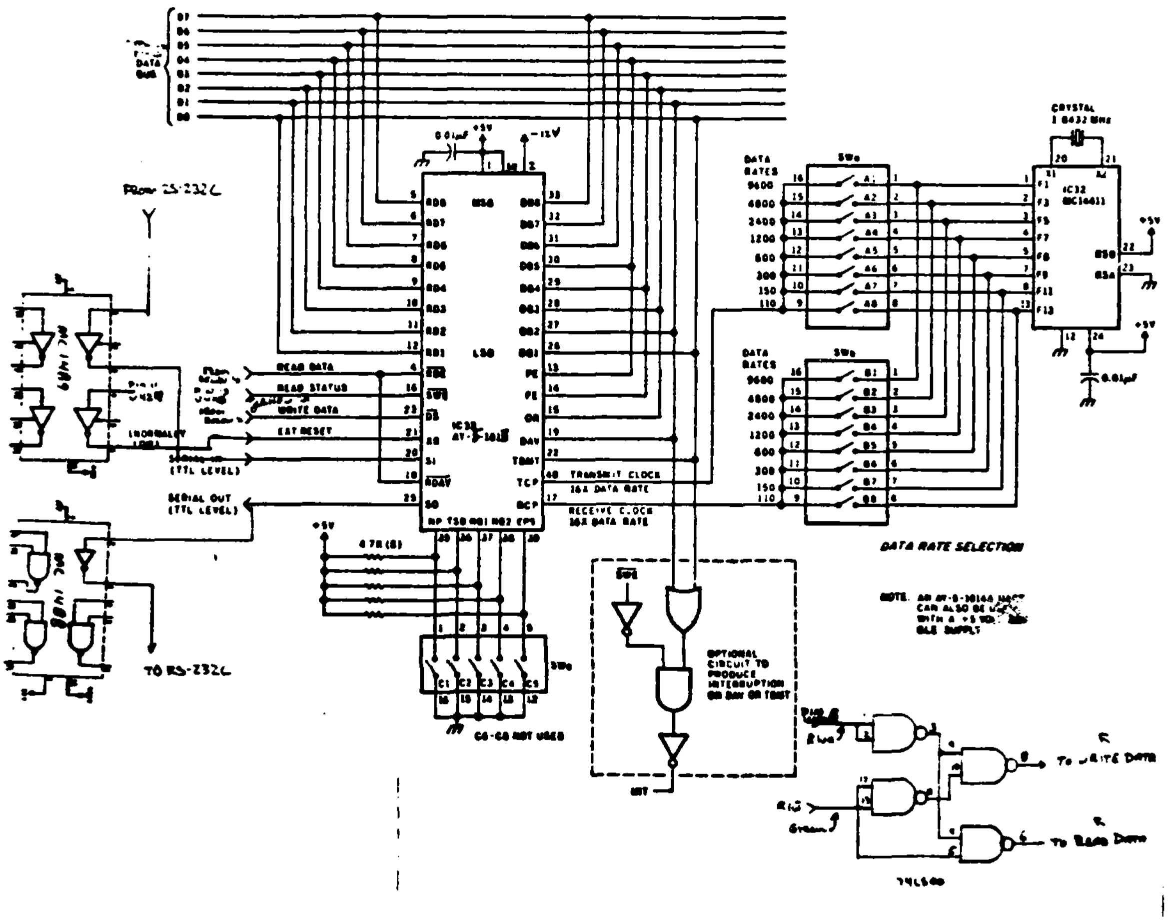
32K Memory Expansion



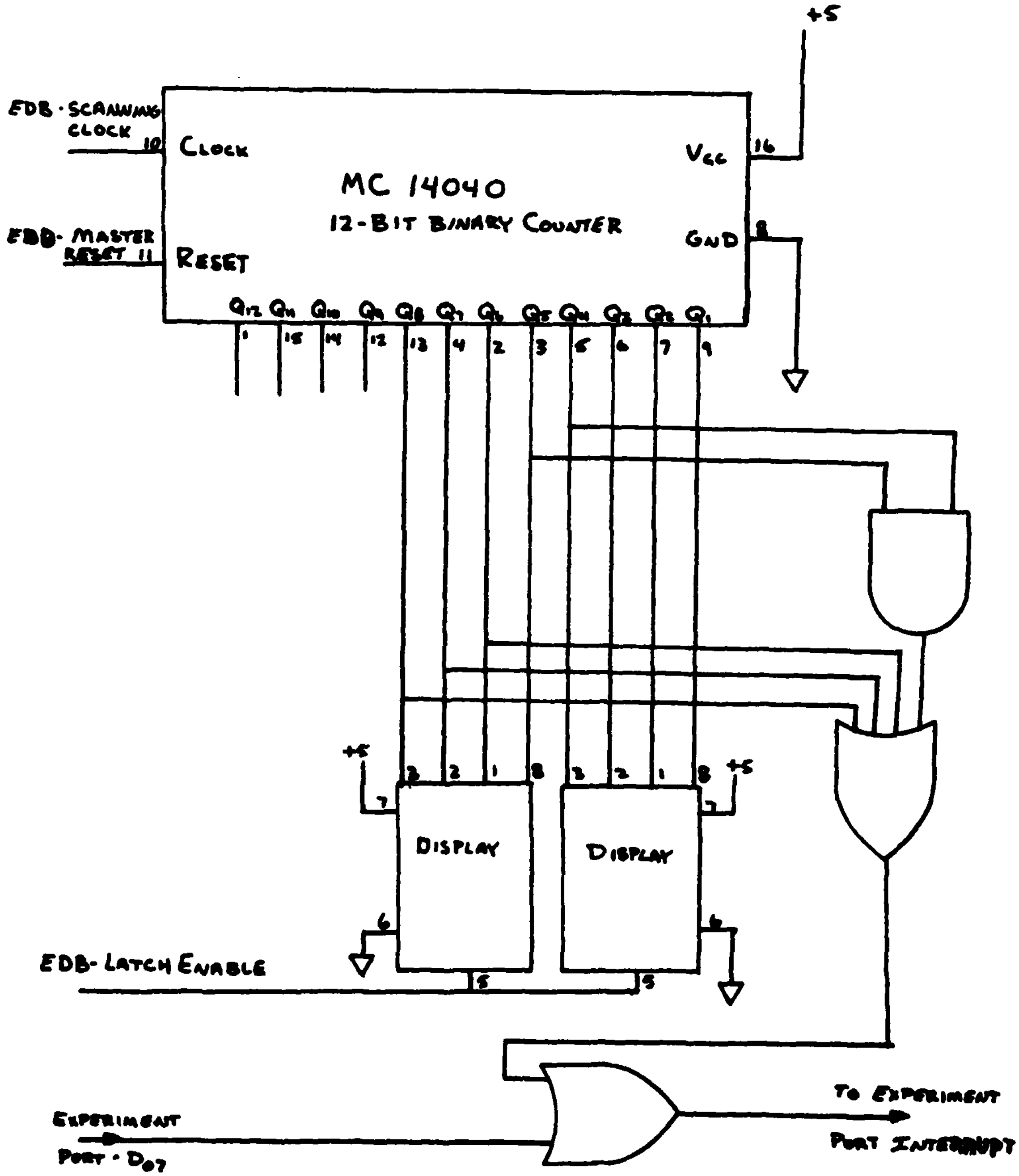
RAM Expansion Board 50-Pin Connector



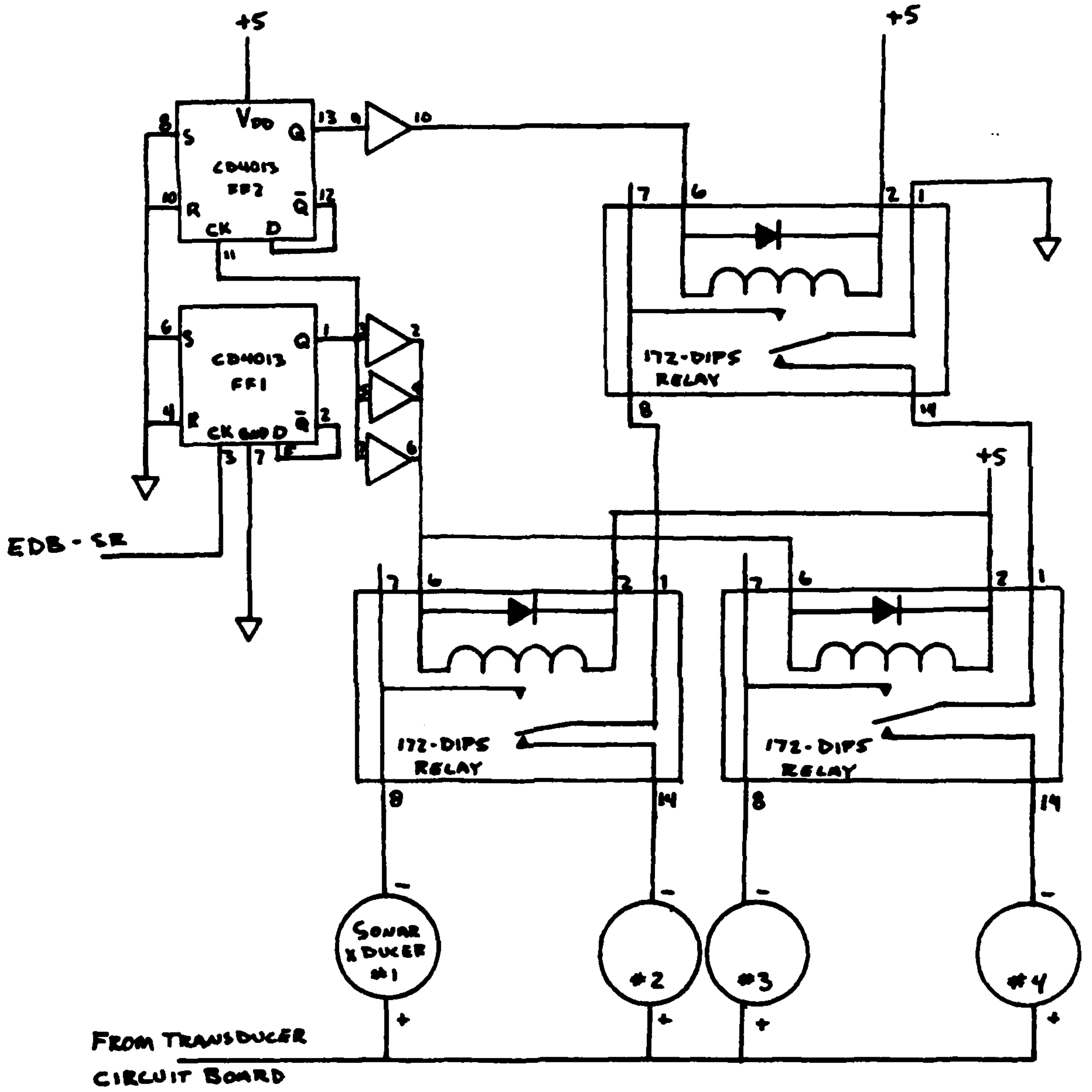
RAM Expansion Board Data Bus Control



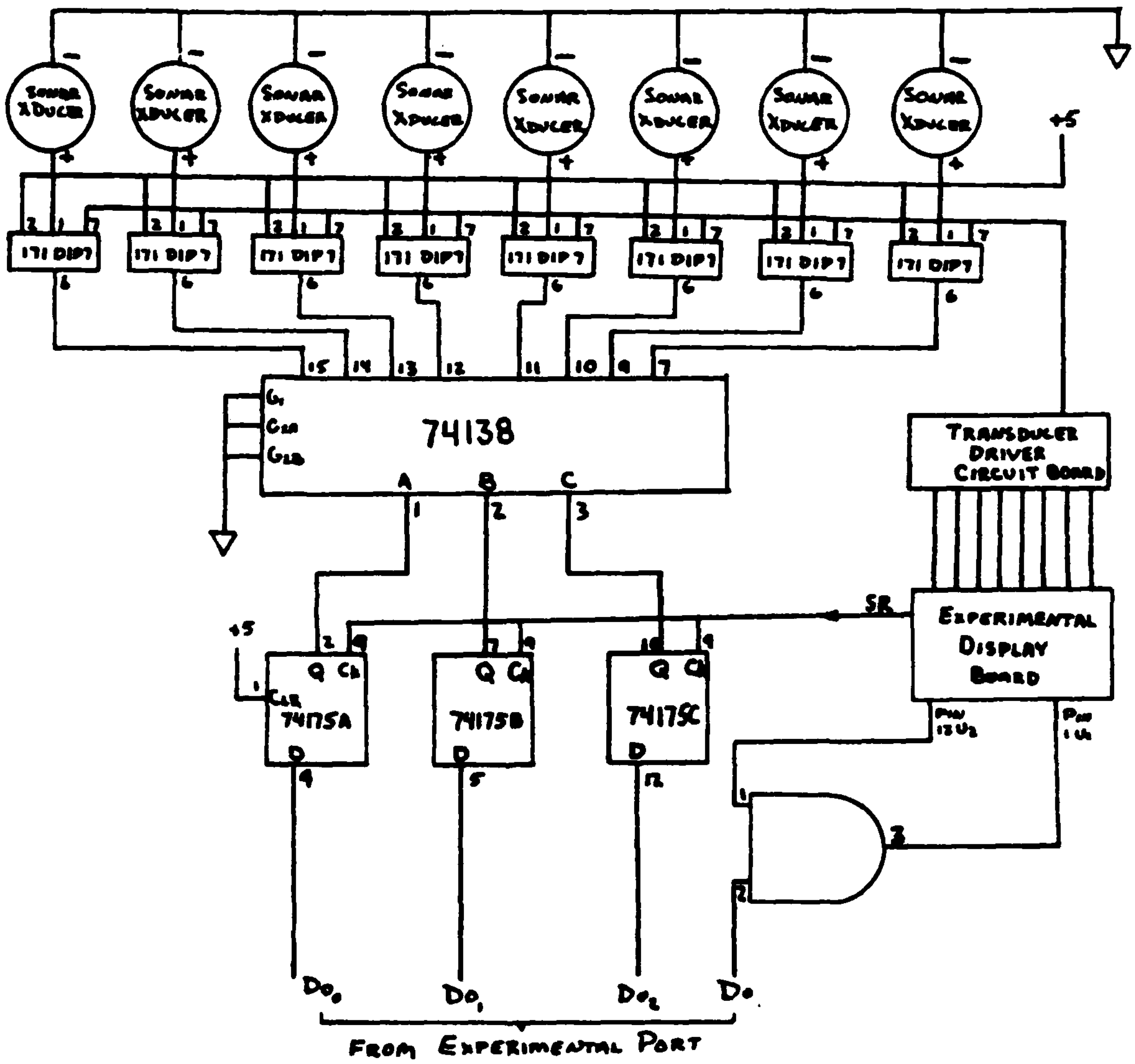
RS-232C Interface



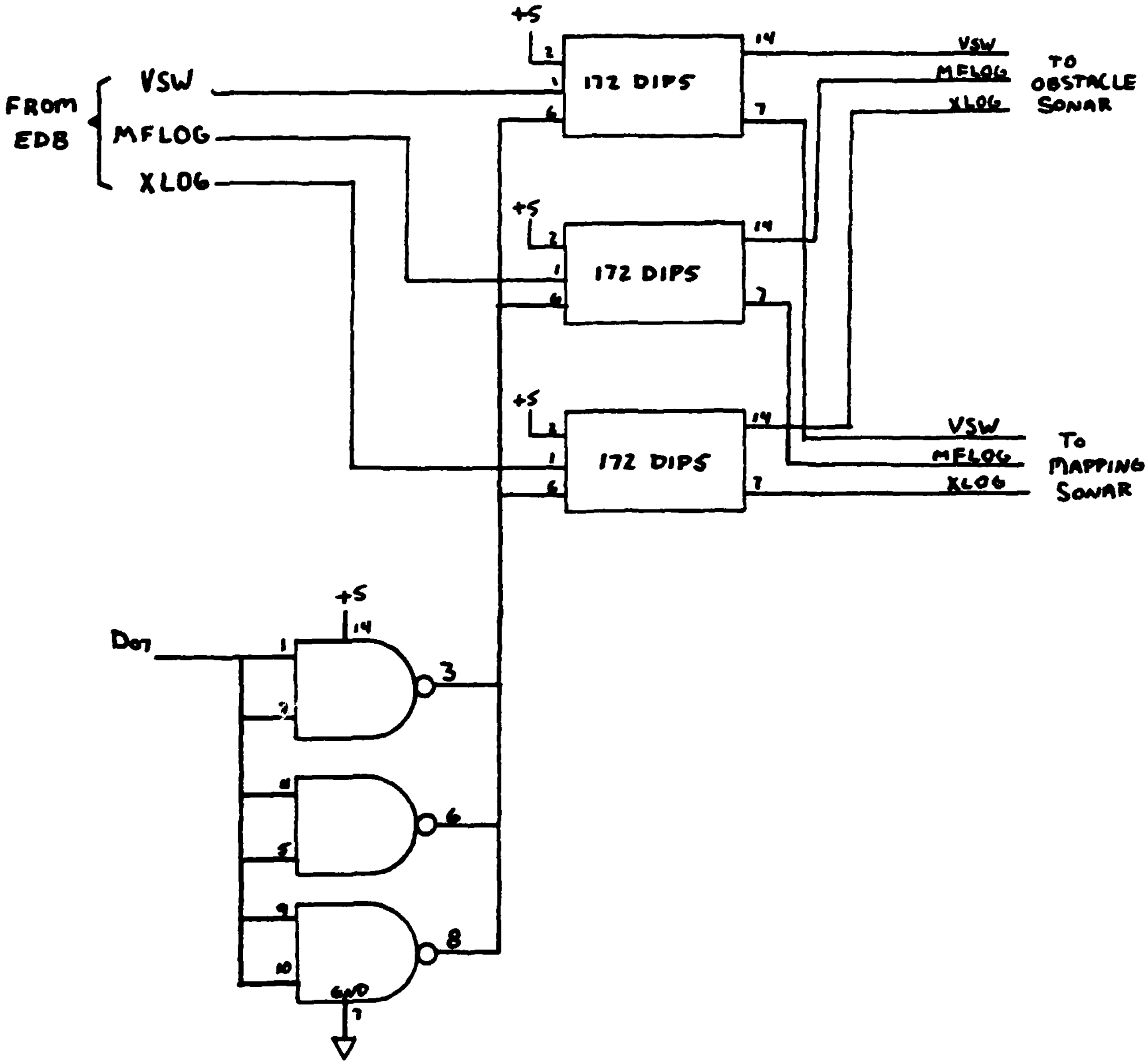
Sonar 8-Bit Timer



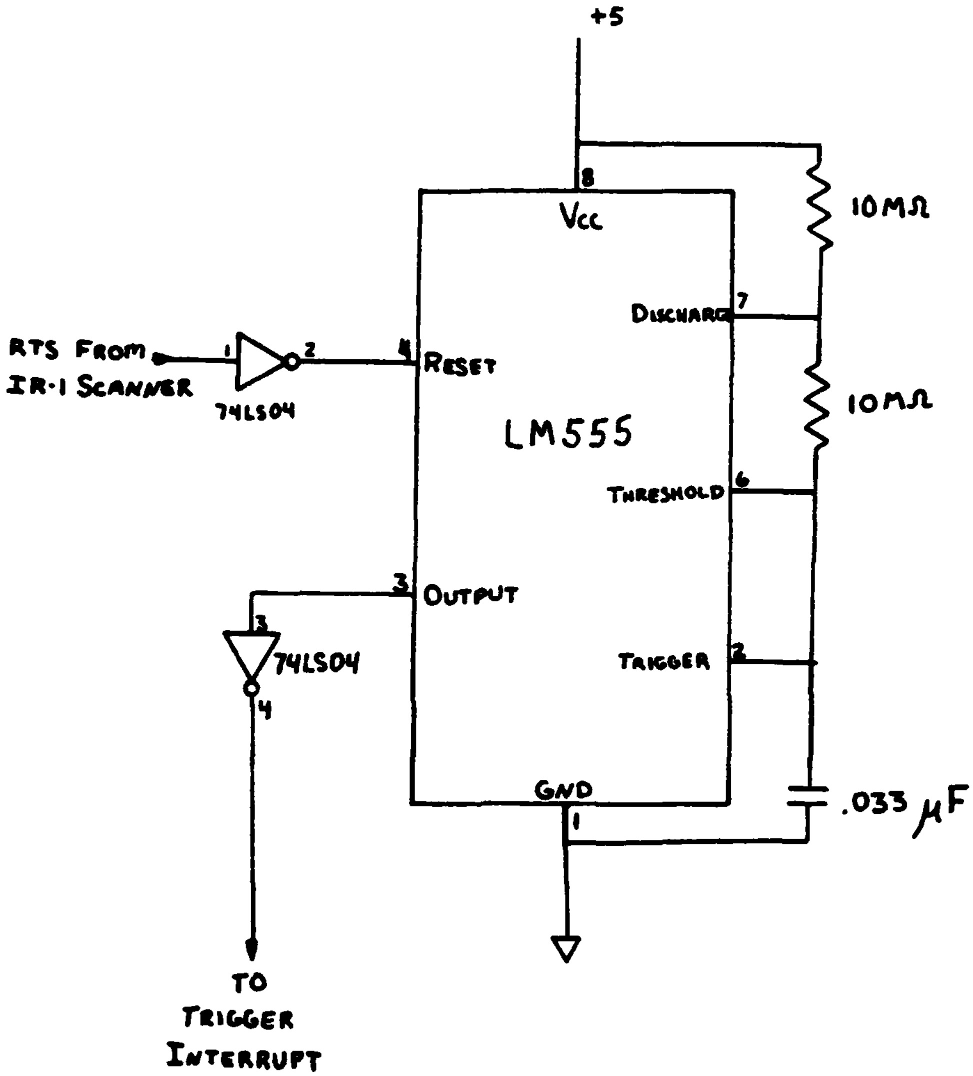
Obstacle Sonar Transducer Selector



Mapping Sonar Transducer Selector



Obstacle/Mapping Sonar Selector



RTS Interrupt Pulse Generator

Appendix H: Initial Specifications for the HERO-1 Robot

SPECIFICATIONS

ET/ETW-18 HERO I ROBOT	Microprocessor	6808.
	Type	8-bit CPU.
	System Clock	895 kHz derived from a 3.58 MHz crystal.
	On-Board Memory	
	ROM	8K with space for optional ROM.
	RAM	4K.
	Display	Six 7-segment LEDs.
	Keyboard	17-key hexadecimal keypad (0-F and RESET). 1 through F are dual-function keys and also enter commands.
	Sensors	
	Sound	
	Frequency Range	200 Hz to 5 kHz.
	Resolution	1 part in 256.
	Sensing Angle	Omnidirectional.
	Light	
	Range	Visible spectrum.
	Resolution	1 part in 256.
	Sensing Angle	About 30 degrees.
	Ultrasonic Ranging	
	Type	Pulsed ultrasonic system (pulses adjustable).
	Transmitter Frequency	32 kHz.
	Resolution	0.42" (1 cm).
	Sensing Angle	About 30 degrees, horizontal and vertical.
	Range	3" (6.62 cm) to 8' (2.44 m).
	Motion	
	Type	Continuous-wave ultrasonic system.
	Transmitter Frequency	35 kHz.
	Sensitivity	Dependent on size and relative movement of object.
	Sensing Angle	Omnidirectional if pointed at a wall.
	Cassette Interface	
	Data Rate	300 baud. Compatible with ETA-3400 Trainer.
	Mark Frequency	2400 Hz.
	Space Frequency	1200 Hz.
	Experimental Breadboard (Interface)	+5 volt and +12 volt supplies, I/O port, user-defined interrupt, read/write line from CPU.
	Special Purpose Controls	Reset key, Abort key, and Sleep switch.
	Power Supply	Two 12-volt battery systems (motor and electronics).
	General	
	Head Rotation	350° using a stepper motor.
	Minimum Turning Radius	12" (30.5 cm).
	Operating Temperature	0°C to 40°C (32°F to 104°F).
	Weight	39 lbs (17.6 kg) with accessories.
	Dimensions	20" high x 18" diameter (50.8 x 45.7 cm).
	Charger	
	Power Requirements	120/240 volts AC, 50/60 Hz, 60 watts (max).
	Output Voltage	27 volts (max) unregulated.
	Output Current	1.9 amperes (max) into fully discharged batteries.
	Recharge Time	10 hours (max) with Robot turned off; longer with Robot on, depending on functions being used.
	Batteries	
	Type	Four 4 ampere-hour rechargeable gel cells.
	Protection	Automatic low-voltage sensor.
ET-18-1 ROBOT ARM ACCESSORY	Movements	
	Horizontal Rotation	350° using turret motor.
	Vertical Plane	150° using shoulder motor.
	Gripper Extension and Retraction	5" (12.7 cm) using the extender motor.
	Wrist Pivot	90° above or below the arm axis (180° total). using the wrist pivot motor.
	Wrist Rotation	350° using the wrist motor.
	Gripper	Opens 3-3/4" (9.53 cm) using the gripper motor.
	Wrist Assembly Rotation	90° at maximum arm extension (curved track optional installed).
	Maximum Payload	16 oz (453.6 grams) with arm horizontal and fully retracted. 8 oz (226.8 grams) with arm horizontal and fully extended.
	Gripper Force	5 oz (142 grams) maximum.
	Weight	3 lbs (1.36 kg).
ET-18-2 SPEECH ACCESSORY	Type	Synthesized phoneme-based system generating 64 basic sounds.
	Reference Pitch	Hardware selectable.
	Inflection	Four levels using software.

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7. AUTHOR(s) Randall J. Owen, III		8. CONTRACT OR GRANT NUMBER(s) --
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Robot, Robotics, Sonar, Barcode, Code 3 of 9, Environmental Mapping, Aircraft Refueling, Laser Barcode Scanner

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The first step in the development of a system to automatically fuel and service aircraft was accomplished. A HERO-1 robot was augmented with ultrasonic sonar and a laser barcode scanner to enable it to rove about and map its environment. Rover software consists of a few simple routines that, when used together, give the rover

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Item 20 continued:

surprisingly complex behavior. The rover avoids all obstacles while looking for landmarks which enable it to generate a sonar map of its environment stored in memory. Steps for follow on work using a stationary computer as either a peripheral for the rover or as the main controller for the system were taken.

In the course of this work, numerous modifications were made to the HERO-1 . The memory was expanded from 4K bytes to 36K bytes. Two sonar systems (one for object detection the other for mapping) using Polaroid transducers and associated control circuitry were added. An RS-232 port to enable more efficient communication between the rover and any peripheral was included. Finally, an Instaread IR-1 Laser Barcode Scanner was installed, enabling the rover to locate designated objects at a range of up to five feet without the cost and time inefficiency of a full vision system.

The results include a sonar map of a test environment made by the rover.

Reply To
Attn of: 1Lt Randall J. Owen III
AFIT/EN
WPAFB, OH 45433

9 Feb 84

Subject: Distribution Authorization

To: Defense Technical Information Center
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